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Assessment of Eastern Georges Bank Atlantic Cod for 2018

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ABSTRACT

The combined 2017 Canada/USA Atlantic cod catches were 526 mt with a quota of 730 mt. Catches in all three research surveys decreased since the 2017 assessment. Both fishery and survey catches showed truncated age structure in recent years.

The VPA “M 0.8” model from the 2013 benchmark assessment was used to provide catch advice in conjunction with a consequence analysis of the uncertainties in the VPA “M 0.8” and ASAP model results and consideration of an empirical approach. The VPA “M 0.8” model assumes a natural mortality (M) of 0.2 on all ages, except ages 6+ which are assumed to have an M=0.8 since 1994; the ASAP model assumes an M=0.2 for all ages and years.

While management measures have resulted in a decreased in relative F since 1995, total mortality has remained high and adult biomass has fluctuated at a low level. The adult population biomass at the beginning of 2018 was estimated at 9,502 mt, which was about 20% of the adult biomass in 1978, and F was estimated to be 0.04 in 2017. There is a retrospective pattern that creates uncertainty around the magnitude of recent estimates of biomass and F, so a Mohn’s rho adjustment was applied to the estimates to help quantify the uncertainty. The rho adjusted values of 2018 biomass and 2017 F were 6,402 mt and 0.053 respectively. High total mortality, low weights at age in the population and poor recruitment have contributed to the lack of rebuilding.

In 2019, a 50% probability of not exceeding fishing reference point F=0.11 corresponds to catches of 860 mt. Due to the 2013 year class progressing through the ages with high natural mortality, there is a >90% risk that adult biomass will decrease from 2019 to 2020, even with no fishing. In 2020, a catch of 668 mt corresponds to a 50% probability of not exceeding F=0.11; however, even with no fishing in 2020 there is a >90% risk of a decrease in age 3+ biomass from 2020 to 2021 due to the 2013 year class entering the ages of high natural mortality. Given the extremely low spawning stock biomass (SSB), management measures should aim to rebuild SSB.

A consequence analysis to understand the risks associated with assumptions of the VPA “M 0.8” and ASAP “M 0.2” model was examined in the projection and risk analysis. The consequence analysis reflects the uncertainties in the assessment model assumptions.

In 2016, an empirical method was developed as one of the approaches for providing quota advice for Eastern Georges Bank cod. This method adjusts recent quotas by recent population biomass trends from three research surveys. The CV weighted average biomass decreased 75% from 2017 to 2018. Application of the empirical method in 2018 produced a median bias corrected slope of 0.96. Scaling recent average quota by the 25^{th}-50^{th}-75^{th} percentiles of bias corrected slope produces quota advice of 600-644-697 mt, respectively.

Considering the low productivity of cod, despite model uncertainties, all assessment results indicate that low catches are needed to promote rebuilding.

INTRODUCTION

The 2017 assessment for Atlantic cod in management unit area 5Zjm of eastern Georges Bank (Figure 1) was updated using the 2013 benchmark model formulations (Claytor and O'Brien 2013) and an empirical approach developed at 2016 TRAC (Brooks et al., 2016). The Canadian and USA fishery information was updated to 2017, including commercial landings and discards, the Department of Fisheries and Oceans Canada (DFO) survey updated to 2018, the National Marine Fisheries Services (NMFS) spring survey updated to 2018 and the NMFS fall survey updated to 2017.

FISHERY

COMMERCIAL FISHERY CATCHES

Combined Canada/USA catches averaged 17,200 mt between 1978 and 1993, peaked at 26,463 mt in 1982, and then declined to 1,683 mt in 1995. They fluctuated around 3,000 mt until 2004 and subsequently declined again. Catches in 2017 were 526 mt, including 15 mt of discards (Table 1; Figure 2). Catches included USA and Canadian discards in all years where discard estimates were available.

In 2017, total Canadian catch (including discards) was 488 mt, amounting to 83.6% of the 584 mt quota. The catches are taken as part of a mixed groundfish fishery occurring primarily between June and December by longline (39%), otter trawl (36%) and gillnet (25%) gears (Figure 3 and Figure 4). All 2017 landings were subject to dockside monitoring. For the Canadian otter trawl fishery on eastern Georges Bank, 130 mm square mesh has been the standard mesh size in codends since 1995. In 2014, a test project with alternative codend meshes of 125 mm square and 145 mm diamond was undertaken for the purpose of improving the catch rate of haddock and reducing cod bycatch relative to haddock catches (Morin 2014). Based on the results, 125 mm square mesh was approved for use starting in 2015.

Discarding of cod from the Canadian groundfish fishery on eastern Georges Bank (EGB) is not permitted. Since 1997 discards of cod have been estimated using the observed ratio of cod to haddock catch (Van Eeckhaute and Gavaris 2004; Hunt et al. 2005; Gavaris et al. 2006, 2007a; Clark et al. 2008) and in 2017 were calculated as 7 mt from the mobile gear fishery (Table 1). The Canadian scallop fishery has not been permitted to land cod since 1996. Since 2005, estimates of cod discards from the scallop fishery have been obtained by applying a 3-month moving average observed discard rate to the effort of the fleet (Gavaris et al. 2007b). In 2017, the estimated discards of cod by the Canadian scallop fishery were 7 mt (Table 1).

Total USA catch (landings and discards combined) was 38 mt for the 2017 calendar year (Table 1; Figure 5). The majority of USA landings were taken by the second calendar quarter with the least amount landed during the fourth quarter (Figure 4). Otter trawl gear accounted for 92%, handline for 6% and gillnet for 3% of the 34 mt landings during 2017.

Discard ratios (discard cod:kept of all species, d:k) in the US fisheries are estimated on a trip basis (Wigley et al. 2008) and total discards (mt) then estimated from the product of d:k and total commercial landings. In the 2012 SAW55 cod benchmark meeting (NEFSC 2013), 'Delphi' determined mortality rates (otter trawl: 75%) were applied to the final estimates of USA discards (Table 1). In July 2013, there was a reduction in the minimum size for the US fishery from 22 inches to 19 inches. The estimated discards of cod in the groundfish fishery were 4 mt in 2017 (Table 1; Figure 5).

The US eastern Georges Bank cod quota for fishing year 2017 (1 May 2017 to 30 April 2018 for groundfish) was set at 146 mt. Monitoring of the US catches relative to the quota was based on Vessel Monitoring Systems (VMS) and a call-in system for both landings and discards. Reporting on the Regional Office webpage (NOAA Fisheries Northeast Multispecies (Groundfish) Monitoring Reports) indicates the US groundfish fishery caught 30.2% of its 146 mt quota.

SIZE AND AGE COMPOSITION

The size and age compositions of the 2017 Canadian groundfish fishery landings were derived from the pooled port and at-sea samples from all principal gears and seasons (Table 2). Landings by length peaked at 55 cm (22 in) for bottom trawl and 61 cm (24 in) for longline. Gillnet caught fewer cod but these fish were larger, with a broad peak range of 73-88 cm (29-35 in) (Figure 6). The combined landings for all gears peaked at 58 cm (23 in) (Figure 7). The Canadian combined cod discards size composition by length was derived from at-sea sampling and peaked at 49 cm (19 in) (Figure 6, Figure 7). Landings by length for the US fishery peaked at 68 cm (27 in) and discards by length peaked at 47 cm (19 in) in 2016 (Figure 8). The 2017 total catch composition peaked at 58 cm (23 in) for the Canadian fishery and at 68 cm (27 in) for the USA fishery (Figure 9).

Otoliths taken from port samples, observer samples and surveys were used to characterize the age composition of the Canadian catch. Catch-at-age composition was obtained by applying quarterly fishery age-length keys to the size composition. Past comparisons of age readings have indicated generally good agreement between DFO and NMFS age readers, (http://www.nefsc.noaa.gov/fbp/QA-QC/). Details of the methodology used for the determination of size and age composition of USA fishery landings and discards on eastern Georges Bank are described in Wang et al. (2015).

The 2017 combined Canada/USA landings and discards fishery age composition, by number, was the highest for the 2013 year class at age 4 (52%) and the 2011 year class at age 3 (24%, Table 3; Figure 10). By weight, the 2013 year class also dominated the 2017 fishery (49%), followed by the 2011 year class (18%, Figure 10). The contribution of fish aged 8 and older continue to be low in recent years, amounting to 0.37% by number and 0.9% by weight in 2017 (Table 3; Figure 10; Figure 11).

Following a decline throughout the 1990s and the early 2000s, lengths and weights at age (WAA) for the eastern Georges Bank cod fishery have either stabilized at low levels or shown varying degrees of improvement (Table 4, Table 5, Figure 12). A recent increase in weight at age is particularly notable for ages 5, 6 and 7, with a 40-60% increase in weights at age since 2011, returning to weights at age seen in the 1980s and 1990s (Figure 12). This trend can be partly attributed to a change in catch contribution by the Canadian gillnet fleet, whose contribution to the total Canadian catch (mt) increased from <10% to 25% since 2011 (Figure 3). Given that this gear catches larger cod, their increasing contribution to the fishery catch could be improving sampling of the larger size classes and consequently increasing the fishery WAA. Weights at age for fish aged 8 and older are not considered reliable due to their intermittent presence in the catch and consequently low sampling intensity.

ABUNDANCE INDICES

RESEARCH SURVEYS

Surveys of Georges Bank have been conducted by DFO every February/March since 1986, and by NMFS each spring (April) since 1968 and fall (October) since 1963. All surveys use a stratified random design (Figure 13 and Figure 14) and historic changes in vessels and nets are documented in Wang et al. (2015). In 2018, the DFO survey was conducted by the Mersey Venture due to unavailability of the usual survey vessels, the CCGS Alfred Needler and the CCGS Teleost. The Mersey Venture is a sister ship to the Teleost, so no conversion factors were necessary. The 2017 NMFS fall survey was completed by NOAA Ship Pisces, also due to the unavailability of the regular vessel, NOAA Ship Henry B. Bigelow. The Pisces and the Henry B. Bigelow are sister ships and no conversion factor was applied to account for this boat change.

The spatial distribution of ages 3 and older cod caught during the 2017 NMFS fall, 2018 DFO and NMFS spring surveys were similar to observations from those surveys over the previous decade, with most fish concentrated along the northern part of Georges Bank (Figure 15, Figure 16, and Figure 17).

The swept area abundance from the DFO survey decreased from 8.3 million fish (2017) to 3.5 million fish in 2018, putting it below the series mean of 5.6 million fish (1986-2018) (Table 6). The 2013 year class at age 5 continued to contribute the most with 46% by number, followed by the 2014 year class at age 4 (15%). The 2017 year class at age 1 contributed 1% of the catch by number and there was no fish older than 8 (Table 6; Figure 18). The 2018 NMFS spring survey catch decreased to 1.7 million from 2017 and remains below the time series mean (5.6 million fish, 1970-2018) (Table 7). Unlike the DFO survey, the 2013 year class (age 5) made a surprisingly low (20%) contribution to the survey catch by number, being exceeded by both the 2015 (age 3) and the 2014(age 4) year classes (34% and 31%, respectively). Although age 9 fish were present in the 2018 Spring NMFS survey catch, there were no fish ages 6 through 8 (Table 7).

The NMFS fall survey catch decreased from 2.6 million to 348 thousand fish in 2017, falling below the series mean of 2.2 million (1970-2017) (Table 8). Although the 2013 year class (age 4) was predominant in the fall survey catch by number (26%), it was closely followed by the 2016 (age 1, 22% by number) and 2015 (age 2, 21% by number) year classes (Table 8; Figure 18). Consistent with trends seen since 2010, the fall survey continues to see few or no fish over the age of 5 (Table 8; Figure 18). It should also be noted that fall survey catches of cod in 2017 were the third lowest in the time series and resulted in particularly low sample sizes, so trends in biological indicators from the 2017 NMFS fall survey should be interpreted with caution.

Survey abundance at age 1 and age 2 indicate that recruitment prior to 1990 was higher, with more frequent larger year classes (Figure 19). Since 1990, there have only been three noticeable recruitment events (2003, 2010, 2013), but the magnitude of these is far less than what was produced in the period before 1990. Overall, the survey abundance at age shows poor recruitment since the 1990 year class and representation of older ages in recent years has decreased (Table 6, Table 7 and Table 8; Figure 18).

In previous years, all three surveys consistently indicated the dominance of the 2013 year class in the catch (Figure 18). However, in the most recent year of data (2018 for spring and 2017 for fall), DFO spring continues to show a strong 2013 year class but both NMFS spring and fall show it as equivalent or lower in abundance than the 2014 and 2015 year

classes (Figure 18). This divergence in survey trends creates uncertainty around the strength of the 2013 year class.

The coefficient of variation (CV) of stratified mean catch number per tow for the three surveys is shown in Table 9 and Figure 20. The catch from all three surveys became more variable after mid-1990s, which can be caused by patchy distribution of cod at low abundance. All three surveys CVs in the most recent year were consistent with trends observed in the previous five years (Figure 20).

Survey swept area biomass decreased from last year for all three surveys, but remains comparable to the levels of stock biomass seen in recent years (Table 10; Figure 21). All three surveys are currently below their respective series means (DFO: 1986-2018; NMFS spring: 1970-2018; NMFS fall: 1970-2017) (Table 10; Figure 21).

The number weighted average weights at age derived from the 2018 DFO and NMFS spring surveys were used to represent the population weight at age for the beginning of the year (Table 11, Figure 22). Survey weights at age (WAA) of cod on eastern Georges Bank decreased gradually throughout the 1990s and early 2000s, and have remained stable at a low level since then (Figure 22). Survey weights at age for ages 5 through 7 do not show a notable improvement in recent years, confirming that increases seen in the fishery WAA are likely caused by gear selectivity (Figure 12, Figure 22).

Fulton's condition factor (K) for all three surveys showed a notable downward trend throughout the series until 2009, when condition began to increase in all three surveys (Figure 23). Cod condition is currently close to the long-term mean for both spring surveys and males in the fall survey, but showed a steep decline for females in the 2017 fall survey (Figure 23). This apparent disparity in survey trends, combined with the low catch in the fall survey in 2017, indicates that the decrease in female condition in the fall of 2017 is likely not a major concern (Figure 23).

The total mortality (Z) was calculated by two age groups (ages 4-5 and ages 6-8) using DFO survey and NMFS spring survey abundance indices separately, and fitted with a loess smooth to help track trends (Figure 24). Total mortality on ages 4 and 5 has been lower than the older group since the 1990s in both surveys, but has begun to converge for the NMFS spring survey in recent years; DFO spring survey continues to show a higher Z on the older ages (Figure 24). There is no indication of a decline in mortality in recent years relative to earlier years.

Total survey Z was also calculated using the Sinclair (2001) approach for all three surveys as was suggested for Georges Bank Yellowtail Flounder at the 2016 TRAC (Sinclair 2001; Brooks and Curran 2016). Age groups used in the calculation varied by survey (DFO: ages 6-9; NMFS spring: ages 5-9; NMFS fall: ages 3-6). Recent Z values on older age groups from the DFO and NMFS spring surveys remain at high values, while Z on the younger ages from the NMFS fall survey remain at low values (Figure 25). Both calculations of Z imply that total mortality on older age groups has remained high throughout the assessment time period, while relative F (fishery catch at age per survey abundance indices) has declined significantly since the 1990s (Figure 26). The increasing occurrence of year and age combinations with no cod observed in the surveys, particularly for the older ages, is problematic for these simple calculations of survey Z.

ESTIMATION AND DIAGNOSTICS

CALIBRATION OF VIRTURAL POPULATION ANALYSIS (VPA)

At the benchmark assessment review in 2013 there was no consensus on a benchmark model; however, the TRAC did agree to provide catch advice based on a virtual population analysis (VPA) “M 0.8” model, in conjunction with a consequence analysis that compares the VPA and ASAP model (presented below) projection results (Claytor and O’Brien 2013). In this assessment update, the VPA used fishery catch statistics and size and age composition of the catch from 1978 to 2017 (including discards). The adaptive framework, ADAPT (Gavaris 1988), was used for calibrating the VPA with trends in abundance from three research bottom trawl survey series: DFO, NMFS spring and NMFS fall. Computational formulae used in ADAPT are described in Rivard and Gavaris (2003a).

In this model, natural mortality (M) was assumed equal to 0.2 for all years and ages, except for ages 6+ since 1994 where it was fixed at 0.8. The data used in the model were:

$C_{a,t}$ =catch at age for ages *a*=1 to 10+ and time *t*=1978-2017, where *t* represents the year during which the catch was taken.

$I_{1,a,t}$ = DFO survey for ages *a*=1 to 8 and time *t*=1986.17, 1987.17… 2017.17, 2018.00.

$I_{2,a,t}$ = NMFS spring survey (Yankee 41) for ages *a*=1 to 8 and time *t*=1978.28, 1979.28, 1980.28, 1981.28.

$I_{3,,a,t}$ = NMFS spring survey (Yankee 36) for ages *a*=1 to 8 and time *t*=1982.28, 1983.28… 2017.28, 2018.00.

$I_{4,a,t}$ = NMFS fall survey for ages *a*=1 to 5 and time *t*=1978.69, 1979.69… 2016.69, 2017.69.

The population was calculated to the beginning of 2018; therefore the DFO and NMFS spring survey indices for 2018 were designated as occurring at the beginning of the year. The benchmark formulations assumed that observation errors for the catch at age data were negligible. Observation errors for the abundance indices at age were assumed to be independent and identically-distributed after taking natural logarithms of the values. Zero observations for abundance indices were treated as missing data, as the logarithm of zero is not defined. In the 2018 assessment, fishing mortality on age 9 for 1978-2013 and 2015-2017 was assumed to be equal to the population weighted average fishing mortality on ages 7 and 8. As there were no age 9 cod caught in the 2014 fishery, the population at age 9 in 2014 was estimated.

This approach is considered a deviation from the 2013 benchmark formulation, but no specific guidance exists on how to address a situation without age 9 cod in the catch at age.

Estimation was based on minimization of the objective function:

$$\sum_{s,a,t}\left(lnI_{s,a,t}-\left(\hat{\kappa}_{s,a}+v_{a,t}\right)\right)^2$$

where *s* indexes survey. The estimated model parameters were:

$v_{a,t} = lnN_{a,t}$ = *ln* population abundance for ages *a*=2 to 9 at beginning of 2018; age 9 in 2014.

$K_{1,a}$ = *ln* DFO survey catchability for ages a=1 to 8 at time t=1986-2018.

$K_{2,a}$ = *ln* NMFS spring survey (Yankee 41) catchability for ages *a*=1 to 8 at time t=1978-1981.

$K_{3,a}$ = *ln* NMFS spring survey (Yankee 36) catchability for ages *a*=1 to 8 at time t=1982-2018.

$K_{4,a}$ = *ln* NMFS fall survey catchability for ages *a*=1 to 5 at time t=1978-2017.

Statistical properties of the estimators were determined using conditional non-parametric bootstrapping of model residuals (Efron and Tibshirani 1993; Rivard and Gavaris 2003a).

For the beginning of 2018, the population abundance estimate of the 2016 year classes at age 2 exhibited the largest relative bias of 14% and relative error of 63% (Table 12). The relative bias for other ages ranged between 3% and 9% and the relative error ranged between 28% and 47%. The population abundance of the 2005 year class at age 9 in 2014 was estimated as 0.06 million, with relative bias of 3% and relative error of 28%. Survey catchability (q) at age progressively increased until age 5 for DFO and age 4 for the NMFS spring surveys; catchability at age for the NMFS fall survey remains very low (Table 12, Figure 27).

The overall fit of model estimated biomass to the DFO, NMFS spring and NMFS fall surveys was generally consistent with the q-adjusted survey trends after 1994 (Figure 28), though at-age residual patterns suggest obvious year effects (Figure 29). Average fishing mortality (F4-9) by time blocks for 1978-1993, 1994-2009 and 2010-2017 was 0.48, 0.28 and 0.18 respectively, which is consistent with fishery management effort trends. The fishery partial recruitment (PR) has domed substantially since 2010, especially when compared to the relatively flat pattern seen in the earlier time periods for ages 6 through 9 (Figure 30). A variety of factors can be contributing to apparent doming of PR, including poor characterization of the commercial catch at age, gear selectivity changes as fishing practice has shifted to avoiding cod, misspecification of model parameters and disagreement between survey and catch trends, especially with respect to smaller year classes. If the doming of PR is real, then F=0.11 may no longer be an appropriate fishing mortality reference point, as it assumes a flat-top PR.

Retrospective analysis was used to detect any bias of consistently overestimating or underestimating fishing mortality, biomass, or recruitment relative to the terminal year estimates. A retrospective pattern emerged in the VPA “M 0.8” model following the 2013 assessment (Wang and O’Brien 2013a), and several approaches have been presented since then to help address the issue (Wang et al. 2015, Legault 2017, Rossi et al. 2017). The Wang et al. (2015) approach focused on the uncertainty around the size of the 2003 year class and has been presented as a sensitivity run ‘est 2003 yc’ in previous assessments (Martin et al. 2017). The size of the 2003 year class affects perception of stock dynamics prior to 2014, and consequently was not updated in the current (2018) assessment. Any discussions of stock dynamics during the 2003-2012 time period should consider both the base model and the latest ‘est 2003 yc’ sensitivity run presented in Martin et al. (2017), to help quantify the uncertainty around the size of the 2003 year class. The use of state-space models (Legault 2017, Rossi et al. 2017) provides an alternative method of addressing the retrospective bias, improving model fit and model diagnostics, and should be examined further during the next benchmark.

Retrospective bias affecting the 2009-2013 estimates from the VPA “M 0.8” model, became evident during the 2017 and 2018 assessments (Figure 31). The current (2018) estimate shows a decrease in biomass to a series low in 2011, followed by an increase since then; this is contrasted by the 2013-2016 assessments which showed biomass remaining relatively stable throughout the 2009-2013 period (Figure 31). Consequently,

the current (2018) estimate of F4-9 shows an increase from 2009 to a peak in 2011-2012 (F4-9 of 0.41 and 0.43 respectively), reaching the highest levels of F since 1995, and quickly descending to an F4-9 of 0.06 in 2014 (Figure 31). Assessments prior to 2017 showed a steady general decrease in F from 2009 until 2014, with no indication of a high peak in 2011-2012 (Figure 31). In comparison, relative F for the spring surveys showed a peak in 2011-2012, but the level of F was substantially lower than that observed during the early 2000s (Figure 26). Several factors including disagreement between survey and catch population trends, error in the catch or model misspecification could be causing this retrospective and additional work is required to address it. This can be achieved either by investigating the cause of the retrospective or by considering methods that address the retrospective without specifically identifying the cause. As stated above, state-space models similar to those presented by Legault (2017) and Rossi et al. (2017) could address the retrospective bias while improving model fit and diagnostics, and should be examined further during the next benchmark.

To help quantify the impact of the retrospective bias on the 2018 assessment, the average Mohn's rho was calculated for the five retrospective relative differences in assessment years 2014-2018. The five-year peel is considered sufficient to determine Mohn's rho (Miller and Legault 2017) while simultaneously avoiding the inclusion of the uncertainty around the size of the 2003 year class. The 2018 values for Mohn's rho were 0.48 for SSB, -0.30 for F, and -0.21 for age 1 recruitment (Table 13).

Palmer (2017) indicated there was a high possibility of misreported U.S. fishery catch for eastern Georges Bank cod from 2010-2015. Although more research to quantify the misreported catch is planned, the errors in catch were not assumed in the current assessment VPA "M 0.8" model. The uncounted misreported catch would potentially impact the retrospective analysis, and subsequently impact the characterization of stock status and provision of catch advice.

STATE OF RESOURCE

The estimates presented below were from the 2018 VPA "M 0.8" model (Table 14, Table 15, and Table 16).

Adult population biomass (ages 3+) declined substantially from 1990 to 1995, fluctuating between 5,900 mt and 18,800 mt since then (Table 14; Figure 32). The increases of age 3+ biomass since 2012 was largely due to the recruitment and growth of the 2010 and 2013 year classes. The adult population biomass at the beginning of 2018 was estimated to be 9,502 mt (80% confidence interval: 7,778 – 12,302 mt) by the 2018 "M 0.8" model, though the emergence of a retrospective pattern indicates that biomass in recent years is overestimated as compared to earlier assessments (Table 14; Figure 31; Figure 32). The rho-adjusted estimate of adult population biomass from the VPA "M 0.8" at the beginning of 2018 was 6,402 mt. An assumption of high natural mortality, lower weights at age in recent years and generally poor recruitment likely have contributed to the lack of sustained rebuilding for eastern Georges Bank cod.

Recruitment at age 1 has been low in recent years. The current estimate of the 2013 year class at 4.4 million fish is the highest estimated recruitment since 1990, but is still about half the average recruitment seen between 1978 and 1990 (Table 15; Figure 32). The 2018 "M0.8" model estimate of the 2010 year class at age 1 is 4 million fish (Table 15; Figure 32). Recruitment for the 2002, 2004, 2007, 2008, 2012, 2015 and 2016 year classes are the lowest on record and the current biomass remains below the level above which chances of higher recruitment increase (Figure 33).

Fishing mortality (population number weighted average of ages 4-9) was high prior to 1994 (Table 16; Figure 34) but declined in 1995 to F=0.11 due to restrictive management measures. There is a retrospective pattern in F that makes estimation of the magnitude and trend in recent F uncertain. The 2018 assessment showed that the 2017 F is currently estimated at 0.04 (80% confidence interval: 0.031 - 0.053), and a rho-adjusted F of 0.053.

PRODUCTIVITY

Trends in recruitment, natural mortality, age structure, fish growth, and spatial distribution typically reflect changes in the productive potential of a population. While management measures have resulted in a decreased rate in relative F since 1995 (Figure 26), total mortality has remained high and adult biomass has fluctuated at a low level. The current biomass is well below 25,000 mt; the threshold above which historically there is a better chance for higher recruitment (Figure 33). Fishery weight at age has shown some signs of improvement for select ages in recent years, but gear selectivity may be contributing to this increase as the survey weights at age do not show an improvement (Table 4; Figure 12). The research survey spatial distribution patterns of adult (age 3+) cod have not changed over the past decade (Figure 15, Figure 16, and Figure 17). High total mortality, low weights at age in the population and poor recruitment have contributed to the lack of rebuilding for eastern Georges Bank cod.

HARVEST STRATEGY

The Transboundary Management Guidance Committee (TMGC) has adopted a strategy to maintain a low to neutral risk of exceeding the fishing mortality reference. At the 2013 benchmark meeting, it was agreed that the current F_{ref}=0.18 (TMGC meeting in December 2002) is not consistent with the VPA “M 0.8” model, and a lower value for F_{ref} would be more appropriate (Claytor and O’Brien 2013). At the 2014 TRAC meeting, it was agreed that F=0.11 was an appropriate fishing reference point for the VPA “M 0.8” model based on the analyses presented (O’Brien and Worcester 2014). This value was derived from an age-disaggregated Sissenwine-Shepherd production model using M=0.8 (Wang and O’Brien 2013b). During the 2016 TRAC meeting, it was noted that due to recent dome-shaped fishery selectivity, F_{4-9} cannot be directly compared to F=0.11 which assumes a flat top partial recruitment (TRAC 2016). When stock conditions are poor fishing mortality rates should be further reduced to promote rebuilding.

OUTLOOK

This outlook is provided in terms of consequences with respect to the harvest reference points for alternative catch quotas in 2019 and 2020 (Gavaris and Sinclair 1998; Rivard and Gavaris 2003b).

Uncertainty about current biomass generates uncertainty in forecast results, which is expressed here as the probability of exceeding F=0.11 in 2019 and 2020, as well as the change in adult biomass from 2019 to 2020 and from 2020 to 2021. The risk calculations assist in evaluating the consequences of alternative catch quotas by providing a general measure of the uncertainties. However, risk calculations are dependent on the data, and model assumptions and do not include uncertainty due to variations in weight at age, PR to the fishery, natural mortality, systematic errors in data reporting or the possibility that the model may not reflect stock dynamics closely enough.

For projections, the average of the most recent three years of fishery and survey weights at age is used for fishery and beginning year population biomass for 2018-2020. The five

year average (2013-2017) recruitment at age 1 is used for 2018-2021 projections. The uncertainties for this estimate are not reflected in the projection. The 2018-2020 PR is based on the most recent five years of estimated PR (Table 17). In accordance with the 2018 TRAC ToR, an additional sensitivity projection was done using a flat-top PR (the average PR for 1994-2012, Table 17), but this sensitivity run is expected to over-inflate the projected catch. The results for this sensitivity run are presented in Table 20 and Table 21, but their use is not advised.

Projections incorporating the rho-adjustment are expected to help quantify the uncertainty around the VPA estimates. Due to time constraints, rho-adjusted projection values were not included in this document, but will be presented at the 2018 TRAC meeting.

2019 Projection and Risk Analysis

Assuming a 2018 catch equal to the 951 mt total quota, both deterministic (Table 18) and stochastic (Table 19; Figure 35) projections based on F reference point 0.11 are provided. In 2019, a 50% risk of not exceeding F=0.11 corresponds to a catch of 860 mt, and a lower risk (25%) corresponds to a catch of 743 mt (Table 19; Figure 35). Due to the 2013 year class progressing through the ages of high natural mortality, there is a >90% risk that adult biomass will decrease from 2019 to 2020, even with no fishing (Table 19, Figure 35).

2020 Projection and Risk Analysis

Assuming a 2018 catch equal to the 951 mt total quota and a 2019 fishing mortality of 0.11, the deterministic projection for 2020 is shown in Table 18. In 2020, a 50% risk of not exceeding F=0.11 corresponds to a catch of 668 mt, while a lower risk (25%) corresponds to a catch of 599 mt (Table 19; Figure 36). Even with no fishing in 2020, there is a >90% risk of a decrease in adult biomass from 2020 to 2021 (Figure 36).

Consequence Analysis (Risks Associated with 2019-2020 Projected Catch)

A consequence analysis to understand the risks associated with assumptions of the VPA "M 0.8" and ASAP "M 0.2" models (Appendix B) was examined. This consequence analysis shows (Table 22):

1. The projected catch (ages 1+) at Fref=0.18 and F=0.11 and percent change in biomass, as if each model represented the "true state" of the resource; and

2. The consequences to fishing mortality and expected biomass (ages 3+) when 'true state' catch levels are removed under the assumptions of the other "alternate state" model.

In 2019, a catch of 860 mt at F=0.11 would result in the 2020 biomass decreasing by 15.3% in the VPA "true state" and decreasing by 14% in the ASAP "alternate state". A catch of 524 mt at F_{ref}=0.18 would result in the 2019 biomass decreasing by 4% based on the ASAP "true state" and a decrease of 13.2% in the VPA "alternate state".

In 2020, a catch of 668 mt at F=0.11 would result in 2021 biomass decreasing by 13.6% in the VPA "true state" and increasing by 26% in the ASAP "alternate state". A catch of 568 mt at Fref=0.18 would result in the 2020 biomass increasing by 25% based on the ASAP "true state", and decreasing by 13.2% based on the VPA "alternate state".

Empirical Approach for Providing Catch Advice

In 2016, an empirical method was developed as one of the approaches for providing quota advice for Eastern Georges Bank cod. This approach was developed collaboratively between the TRAC scientists and is described in Brooks et al. 2016. The empirical method adjusts recent quotas by recent population biomass trends from three research surveys

(DFO spring, NMFS spring, and NMFS fall). The combined CV weighted biomass index from 1987 onward is fit by a robust least square loess smoother, and the slope in 3 year intervals is calculated (on log-scale). The most recent 3-year block trend is used to adjust recent quotas and uncertainty around the trend was derived by bootstrapping from the original loess fit. This method is essentially a constant exploitation approach, which relies on recent quotas and assumes that these quotas reflect sustainable catch levels.

The three normalized biomass indices are reported in Table 23 and are plotted in Figure 37. All three indices decreased below the series average from 2017 to 2018 (2016 to 2017 for fall), and consequently so did the combined biomass (Table 23, Figure 38).

The loess fit and 90% confidence intervals from 1000 bootstrap replicates are shown in Figure 39. The estimated 3 year block slope and uncertainties are shown in Figure 40. The values of the median slope and other percentiles are reported in Table 24. Percentiles reflect uncertainty in the estimated 3-year average biomass trend from the robust loess smooth, rather than risk. The percentiles reflect the probability that the true average 3-year trend is within a given bound.

The recent three year average of quotas is 668.3 mt (650 mt in 2015; 625 mt in 2016; 730 mt in 2017). The median of bootstrap bias-adjusted slope estimates for survey years 2015-2017 (NMFS fall) and 2016-2018 (DFO and NMFS spring) is 0.96 using the robust regression fit. The 25th and 75th percentiles are 0.90 and 1.04, respectively. Applying the median slope to the recent average quota (668.3 mt) produces a 2019 quota advice of 644 mt. Applying the 25th and 75th percentiles of bootstrapped slope estimates produces quota advice of 600 mt and 697 mt, respectively (Table 25).

Model Performance

Catch in 2016 was 537 mt out of a 625 mt quota. The VPA conducted in 2017 (Figure 41, top) estimated a 14% increase in 2016 biomass compared to what was projected last year. The ASAP conducted in 2017 predicted a 40% increase in 2016 SSB compared to what was predicted last year; however, the retrospective pattern was large enough to warrant adjustment, and the ρ-adjusted SSB is just 2% greater than what was forecast last year. For the current year, catch in 2017 was 526 mt of the 730 mt quota (72%), yet the VPA estimated a 17% decline in SSB between 2017 and 2018, and projected SSB that is 7% and 21% lower than 2017 for Fref projections in 2019 and 2020 (Figure 41, bottom). The ASAP estimated a 31% decline between 2017 and 2018 SSB, with projected SSB that is 26% and 29% lower than 2017 for Fref catches in 2019 and 2020. This indicates continued overestimation of biomass and catch.

The modelling approach for the empirical method was designed to capture trends in the increase/decrease of the population while at the same time avoiding year effects in any one survey or dramatic changes in surveys by the following modeling decisions:

i) the observation for a given year reflects the average of all 3 surveys, which are weighted by their CV so that more uncertain values have less influence;

ii) a loess smoother is fit to the time series of the survey average, where the fit at any given point is informed by 30% of the surrounding data;

iii) the fit of the loess smooth is determined by locally weighted robust least squares, which refits the smoother twice and downweights outliers;

iv) the slope to adjust quota is the average of the log-scale slope of most recent 3 years of the fitted loess smooth.

Despite these steps, the loess smooth is still subject to inherent uncertainty at the end of the fitted time series, because there are no points to the right to aid in fitting the smooth—all information comes from the terminal points and 30% of data to the left (Figure 42). When one more year of survey data is available in the next year's assessment, the moving window and locally weighted fit feature of loess lead to the newly added data point having a heavy impact on the fit because it is closest to that evaluation point. When there is a dramatic change in magnitude of the newly added survey data, it could cause a "retrospective" pattern. This explains the dramatic change in the loess fit between years 2017 and 2018, and consequently in the estimated slope (Figure 43). This is not something that can be controlled by the empirical approach as it is currently applied. One approach to reduce future risk of this occurrence would be to impose a limit on the % change that is estimated for the slope. For example, the fit in 2017 estimated a median slope of 1.76 (76% increase), whereas the addition of the 2018 data reduced the estimated 2017 slope to 0.957 (4.6% decrease; Table 24). Another approach, considering the relatively flat slope now indicated in Figure 43d, would be to hold quota constant for several years until multiple years of survey data indicate that the population is increasing.

SPECIAL CONSIDERATIONS

Table 26 summarizes the performance of the management system. It reports the TRAC advice, TMGC quota decision, actual catch, and realized stock conditions for this stock. Fishing mortality and trajectory of ages 3+ biomass from the assessment following the catch year are compared to results from this assessment. These comparisons were kindly provided in 2011 by Tom Nies (staff member of the New England Fishery Management Council, NEFMC) and updated for this assessment.

The consequence analysis reflects the uncertainties in the assessment model assumptions. Considering the current poor stock conditions, despite these uncertainties, all assessment results indicate that low catches are needed to promote rebuilding.

Performance of the VPA and ASAP for Eastern Georges Bank cod was poor and seemed to be getting worse with time with regard to model diagnostics. Some of the diagnostic issues were poor fits to the survey data and significant retrospective patterns in biomass, fishing mortality, and recruitment, indicating an undiagnosed misspecification in the model. The VPA and ASAP modeling approaches are becoming increasingly unreliable for providing management advice.

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TABLES

Table 1. Catches (mt) of cod from eastern Georges Bank, 1978 to 2017

Year	Canada				USA			Total
Year	Landings	Discards Scallop	Discards Groundfish	Total	Landings	Discards	Total	
1978	8,777	98	-	8,875	5,502	-	5,502	14,377
1979	5,979	103	-	6,082	6,408	-	6,408	12,490
1980	8,066	83	-	8,149	6,418	-	6,418	14,567
1981	8,508	98	-	8,606	8,092	-	8,092	16,698
1982	17,827	71	-	17,898	8,565	-	8,565	26,463
1983	12,131	65	-	12,196	8,572	-	8,572	20,769
1984	5,761	68	-	5,829	10,558	-	10,558	16,387
1985	10,442	103	-	10,545	6,641	-	6,641	17,186
1986	8,504	51	-	8,555	5,696	-	5,696	14,251
1987	11,844	76	-	11,920	4,793	-	4,793	16,713
1988	12,741	83	-	12,824	7,645	-	7,645	20,470
1989	7,895	76	-	7,971	6,182	84	6,267	14,238
1990	14,364	70	-	14,434	6,414	69	6,483	20,917
1991	13,467	65	-	13,532	6,353	112	6,464	19,997
1992	11,667	71	-	11,738	5,080	177	5,257	16,995
1993	8,526	63	-	8,589	4,019	57	4,077	12,665
1994	5,277	63	-	5,340	998	5	1,003	6,343
1995	1,102	38	-	1,140	543	0.2	544	1,683
1996	1,924	56	0.0	1,980	676	1	677	2,657
1997	2,919	58	428	3,405	549	6	555	3,960
1998	1,907	92	273	2,272	679	7	686	2,959
1999	1,818	85	253	2,156	1,195	9	1,204	3,360
2000	1,572	69	0.0	1,641	772	16	788	2,429
2001	2,143	143	0.0	2,286	1,488	146	1,634	3,920
2002	1,278	94	0.0	1,372	1,688	9	1,697	3,069
2003	1,317	200	-	1,528	1,851	85	1,935	3,463
2004	1,112	145	-	1,257	1,006	57	1,063	2,321
2005	630	84	144	859	171	199	370	1,228
2006	1,096	112	237	1,445	131	94	226	1,671
2007	1,108	114	0.0[1]	1,222	234	279	513	1,735
2008	1,390	36	103	1,529	224	20	244	1,774
2009	1,003	69	137	1,209	433	147	580	1,789
2010	748	44	48	840	357	97	454	1,294
2011	702	29	13	743	267	20	287	1,030
2012	395	42	31	468	96	52	148	616
2013	385	18	21	424	24	16	40	464
2014	430	15	13	458	114	2	116	574
2015	472	13	7	492	111	5	116	608
2016	428	9	3	440	92	5	97	537
2017	474	7	7	488	34	4	38	526
Min	385	7	0	424	24	<1	38	464
Max	17,827	200	428	17,898	10,558	279	10,558	26,463
Ave	4,953	74	90	5,186	3,017	62	3,061	8,130

[1] Discards for the Mobile Fleet were calculated to be 0. Discards for the Fixed Gear fleet were not calculated due to low observer coverage.

Table 2. Length and age samples from the USA and Canadian fisheries on eastern Georges Bank. For Canadian fisheries, at-sea observer samples are included since 1990. The first quarter age samples are supplemented with USA fishery age samples from 5Zjm for 1978-1986 and DFO survey age samples for 1987-2016; the numbers are shown in brackets. The highlighted numbers include samples from western Georges Bank.

Year	USA		Canada	
	Lengths	Ages	Lengths	Ages
1978	2,294	384	7,684	1,364
1979	2,384	402	3,103	796(205)
1980	2,080	286	2,784	728(192)
1981	1,498	455	4,147	897
1982	4,466	778	4,705	1,126(268)
1983	3,906	903	3,822	754(150)
1984	3,891	1,130	1,889	1,243(858)
1985	2,076	597	7,031	1,309(351)
1986	2,145	643	5,890	991(103)
1987	1,865	524	9,133	1,429(193)
1988	3,229	797	11,350	2,437(510)
1989	1,572	347	8,726	1,561
1990	2,395	552	31,974	2,825(1,153)
1991	1,969	442	27,869	1,782
1992	2,048	489	29,082	2,215(359)
1993	2,215	569	31,588	2,146
1994	898	180	27,972	1,268
1995	2645	14	6,660	548
1996	4,895	1,163	26,069	828
1997	1,761	82	31,617	1,216
1998	1,301	338	26,180	1,643
1999	726	228	26,232	1,290(410)
2000	500	121	20,582	1,374
2001	1,434	397	19,055	1,505
2002	1,424	429	16,119	1,252
2003	1,367	416	19,757	1,070
2004	1,547	517	18,392	1,357
2005	297	65	23,937	1,483(697)
2006	446	151	44,708	1,460(648)
2007	589	183	141,607	1,647(456)
2008	972	295	64,387	1,709(495)
2009	1,286	326	48,335	1,725(246)
2010	1,446	333	30,594	1,455(433)
2011	1,203	213	40,936	1,655(536)
2012	598	746[1]	49,447	1,115(216)
2013	2,951	842	75,275	1,334(319)
2014	547	85	50,501	1,141(184)
2015	4,677	1,049[2]	74,028	970 (202)
2016	715	149	76,869	990 (282)
2017	4,120	1,150[2]	50,902	1,039 (334)[3]

[1] Age and length data supplemented with ages from statistical areas 522 and 525.
[2] Age and length data supplemented with ages from statistical area 522.
[3] Survey ALK used to supplement quarter 1 age and length data for scallop discards only.

Table 3. Annual catch at age numbers (thousands) for eastern Georges Bank cod for 1978-2017. Dash indicates no fish.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1978	1	8	108	3,644	1,167	394	163	127	22	23	6	2	1	0.1	0.3	0.4	0.2	5,668
1979	1	15	890	735	1,520	543	182	74	61	11	3	2	1	0.01	1	-	-	4,037
1980	2	6	973	1,650	301	968	354	97	26	46	16	4	1	-	-	-	-	4,445
1981	3	35	860	1,865	1,337	279	475	181	96	59	21	2	1	-	-	-	-	5,216
1982	0.01	15	3,516	1,971	1,269	1,087	196	399	155	49	14	22	6	3	4	1	-	8,707
1983	10	22	783	2,510	1,297	562	398	118	182	102	25	28	12	1	3	1	0.07	6,055
1984	0.1	17	231	805	1,354	546	377	279	39	90	38	17	7	2	3	-	1	3,806
1985	33	9	2,861	1,409	661	987	271	110	110	21	27	3	4	1	1	0.1	-	6,508
1986	1	41	451	2,266	588	343	456	68	48	29	4	8	1	-	-	-	-	4,303
1987	2	22	4,116	846	1,148	163	132	174	41	24	8	3	1	0.06	-	-	-	6,680
1988	1	23	289	4,189	680	855	130	116	182	52	21	13	4	1	0.05	0.1	-	6,556
1989	1	18	680	811	1,983	228	373	56	40	59	15	7	5	0.1	0.4	-	-	4,278
1990	1.1	16	726	3,109	1,038	1,374	145	153	12	12	24	3	2	1	-	0	0.002	6,617
1991	0.4	63	991	1,008	1,927	904	746	105	69	21	11	8	4	2	0.4	1	-	5,862
1992	-	68	2,581	1,379	460	889	314	315	45	34	3	5	2	1	-	-	-	6,096
1993	-	10	501	1894	909	299	359	133	97	25	17	3	0.08	0.2	-	-	-	4,246
1994	1	6	182	483	788	270	45	61	30	21	2	1	-	0.1	0.01	0.009	-	1,889
1995	3	1	57	237	94	105	18	7	4	4	0.1	0.08	0.009	-	-	-	-	531
1996	0.1	5	40	234	398	79	60	13	4	3	0.3	0.1	-	-	0.003	-	-	837
1997	1	9	148	205	358	358	84	37	13	4	1	1	0.05	-	-	-	-	1,219
1998	0.1	5	101	314	161	158	134	23	13	4	1	0.3	0.6	0.04	-	-	-	916
1999	0.1	9	79	483	337	109	61	57	14	2	1	0.08	-	0.01	-	-	-	1,152
2000	1	3	62	110	380	151	37	22	12	3	0.2	0.3	0.005	-	0.08	-	-	783
2001	1	3	107	511	211	398	105	32	17	7	1	0.3	0.07	-	-	-	-	1,394
2002	1	1	10	125	447	108	156	30	9	6	2	1	0.4	-	0.04	-	-	896
2003	13	-	35	148	243	405	81	89	19	4	1	0.3	-	-	-	-	-	1,039
2004	-	23	12	140	151	147	139	35	30	7	1	1	0.2	-	0.009	0.002	0.02	686
2005	-	4	71	45	201	50	34	35	10	5	1	0.02	0.1	0.1	0.004	0.002	-	457
2006	-	3	19	226	78	195	48	18	18	2	2	0.3	0.1	-	-	-	-	608
2007	0.005	2	53	62	421	34	85	11	7	7	0.4	0.1	-	-	-	-	-	682
2008	-	1	45	141	61	249	15	33	4	2	1	0.1	-	0.012	-	-	-	552
2009	1	7	43	200	139	46	137	9	10	1	1	0.05	-	-	-	-	-	594
2010	0.02	3	44	96	211	74	15	35	3	2	0.3	0.04	0.003	-	-	-	-	481
2011	-	9	43	76	93	115	26	12	7	0.2	0.2	0.006	-	-	-	-	-	382
2012	-	2	70	105	49	29	25	6	1	1	0.02	-	-	-	-	-	-	289
2013	0.5	1	27	112	52	11	7	2	0.4	0.03	0.08	-	-	-	-	-	-	212
2014	-	4	17	82	103	28	4	0.3	0.1	-	-	-	-	-	-	-	-	238
2015	-	1	67	38	71	47	6	1	0.03	0.03	0.3	0.002	-	-	-	-	-	231
2016	-	4	15	99	37	32	21	3	0.2	0.001	-	-	-	-	-	-	-	210
2017	0.04	0.5	12	43	92	10	15	5	1	0.005	-	-	-	-	-	-	-	177

Table 4. Average (number weighted) fishery weights at age (kg) of cod from eastern Georges Bank.

Year/Age	1	2	3	4	5	6	7	8	9	10	Ave
1978	0.44	1.26	2.07	2.72	3.72	5.41	5.61	8.28	7.50	11.32	4.83
1979	0.73	1.45	1.52	3.28	4.45	6.59	9.41	9.62	9.86	14.18	6.11
1980	0.38	1.24	2.21	3.07	4.96	6.29	7.22	11.46	10.41	12.54	5.98
1981	0.52	1.28	1.99	3.06	4.54	6.50	8.02	9.25	11.62	15.19	6.20
1982	0.56	1.30	2.13	3.61	5.01	6.76	8.51	9.86	11.86	13.98	6.36
1983	0.90	1.49	2.21	3.10	4.60	6.10	7.81	10.15	11.47	13.20	6.10
1984	0.68	1.60	2.31	3.42	4.76	6.09	8.30	9.35	11.16	12.03	5.97
1985	0.54	1.32	1.81	3.19	4.55	5.95	7.91	9.60	10.75	12.52	5.81
1986	0.54	1.36	2.43	3.30	4.83	6.70	8.08	9.20	11.38	11.46	5.93
1987	0.58	1.46	2.38	3.93	5.38	7.23	8.76	9.46	11.27	12.01	6.25
1988	0.62	1.17	2.19	3.07	4.91	6.10	8.27	9.89	11.14	12.49	5.99
1989	0.62	1.27	1.96	3.35	4.89	6.02	6.79	9.80	10.70	12.77	5.82
1990	0.69	1.55	2.38	3.22	4.59	6.04	7.80	9.81	11.19	12.82	6.01
1991	0.75	1.52	2.42	3.14	4.24	5.53	7.45	9.46	9.18	13.28	5.70
1992	0.86	1.41	2.28	3.32	4.24	5.66	6.80	8.66	11.22	14.85	5.93
1993	0.60	1.40	2.11	2.84	4.29	5.40	6.76	8.29	9.14	11.13	5.19
1994	0.60	1.33	2.14	3.44	4.39	6.42	7.19	8.15	7.97	11.40	5.30
1995	0.32	1.32	2.12	3.35	4.94	6.38	10.10	10.01	10.44	15.35	6.43
1996	0.51	1.42	2.17	3.05	4.70	5.83	6.42	8.96	10.35	10.38	5.38
1997	0.67	1.42	2.07	2.93	3.86	5.36	7.26	8.31	11.48	9.88	5.32
1998	0.70	1.34	2.15	2.98	3.97	5.33	6.59	7.82	10.23	12.88	5.40
1999	0.54	1.30	1.97	3.10	3.91	5.48	6.27	7.54	9.38	13.52	5.30
2000	0.60	1.33	1.97	2.90	4.02	4.70	5.72	6.77	8.35	14.05	5.04
2001	0.21	0.93	1.84	2.74	3.58	4.87	5.22	7.27	8.65	11.07	4.64
2002	0.33	1.20	1.96	2.84	4.01	4.88	6.41	8.23	7.98	10.11	4.80
2003	-	1.24	2.12	2.71	3.53	4.24	5.47	6.84	7.63	8.13	4.66
2004	0.24	1.23	1.84	2.77	3.46	4.56	5.24	7.24	8.54	8.64	4.38
2005	0.40	0.83	1.56	2.35	3.49	4.50	4.85	6.74	7.88	9.26	4.19
2006	0.27	0.64	1.73	2.30	3.29	4.28	6.10	5.78	6.89	7.18	3.85
2007	0.46	1.04	1.61	2.32	2.99	3.91	6.10	6.84	6.90	9.35	4.15
2008	0.30	1.27	2.22	2.79	3.65	5.03	5.82	7.92	7.97	8.73	4.57
2009	0.66	1.13	1.92	3.03	3.71	4.51	5.74	6.73	10.00	10.26	4.77
2010	0.48	1.28	2.04	2.53	3.38	3.44	5.10	6.08	8.84	10.87	4.40
2011	0.31	1.08	1.72	2.56	3.51	4.28	4.23	6.06	9.85	9.37	4.30
2012	0.29	0.93	1.66	2.64	3.69	4.10	4.64	5.70	5.33	5.23	3.42
2013	0.33	1.01	1.85	2.77	3.73	4.86	5.37	5.87	7.89	7.17	4.09
2014	0.30	0.98	2.10	2.60	3.48	4.49	6.24	8.26	-	-	3.56
2015	0.42	1.17	1.97	3.21	4.00	5.09	7.64	13.28	10.41	6.31	5.35
2016	0.14	0.75	1.83	2.54	4.40	4.59	5.87	7.61	15.15	-	4.76
2017	0.19	1.04	1.78	2.79	4.85	6.25	6.94	7.08	11.21	-	4.69
Min	0.14	0.64	1.52	2.30	2.99	3.44	4.23	5.70	5.33	5.23	3.42
Max	0.90	1.60	2.43	3.93	5.38	7.23	10.10	13.28	15.15	15.35	6.43
Avg.[1]	0.25	0.99	1.86	2.84	4.42	5.33	6.82	9.32	12.26	6.31	4.93

[1]for 2015-2017

Table 5. Average (number weighted) fishery length at age (cm) of cod from eastern Georges Bank.

Year/Age	1	2	3	4	5	6	7	8	9	10	Ave
1978	35.4	48.9	58.0	63.2	70.1	79.2	79.8	92.8	89.2	102.0	71.8
1979	39.8	51.6	52.7	68.0	75.3	85.1	97.0	97.6	98.7	112.0	77.8
1980	34.2	49.1	59.3	66.4	78.0	84.2	88.1	103.6	100.4	107.7	77.1
1981	35.6	49.5	57.3	66.4	76.0	86.0	91.9	96.3	103.0	110.9	77.3
1982	37.8	49.8	58.3	69.9	78.3	86.8	93.9	98.1	105.1	111.4	78.9
1983	43.7	52.2	59.6	66.8	76.0	83.9	91.6	99.8	104.2	108.6	78.7
1984	38.5	53.9	60.6	69.0	77.0	83.8	92.8	96.9	102.6	105.2	78.0
1985	37.5	49.9	55.6	67.3	75.7	83.2	91.4	97.2	101.0	106.4	76.5
1986	37.6	50.6	61.5	67.9	76.7	86.4	92.3	96.1	102.6	103.0	77.5
1987	37.7	51.8	60.9	72.0	80.4	88.8	94.9	97.4	103.5	105.0	79.3
1988	38.2	48.3	59.5	66.2	77.7	83.6	93.2	99.2	103.4	107.4	77.7
1989	38.1	49.9	57.5	68.4	77.4	82.9	86.1	99.2	102.0	108.6	77.0
1990	40.0	52.9	61.0	67.4	75.8	82.8	90.7	98.9	103.8	108.8	78.2
1991	40.2	52.5	61.5	66.7	73.7	80.3	89.6	97.5	95.9	110.0	76.8
1992	42.8	51.4	60.3	68.3	74.1	82.1	86.9	94.1	103.7	114.3	77.8
1993	37.8	51.2	58.9	65.0	74.2	80.7	87.2	93.7	95.5	104.0	74.8
1994	37.9	49.9	58.9	69.0	74.6	84.7	88.8	92.2	90.7	104.0	75.1
1995	29.4	50.6	58.9	68.4	78.7	85.5	100.4	99.8	101.0	114.3	78.7
1996	36.0	51.2	59.0	66.2	76.5	83.1	84.4	94.5	100.8	101.6	75.3
1997	39.4	51.0	58.2	65.1	72.0	80.3	89.6	93.7	104.9	99.3	75.4
1998	40.4	49.8	58.8	65.7	72.7	80.5	86.3	91.7	100.8	108.9	75.6
1999	36.6	49.7	57.4	67.0	72.3	81.3	85.5	90.7	97.8	111.0	74.9
2000	38.0	50.4	57.5	65.2	72.8	76.6	82.1	86.8	93.0	111.8	73.4
2001	28.4	44.9	56.1	64.0	69.9	77.6	79.1	89.2	95.3	102.6	70.7
2002	31.6	48.6	57.7	65.2	73.1	77.9	85.4	92.6	92.1	99.5	72.4
2003	-	48.3	59.2	64.4	70.4	74.6	81.2	87.4	90.6	91.6	74.2
2004	25.6	48.2	55.8	64.7	69.7	76.0	79.8	89.0	93.9	94.0	69.7
2005	32.7	42.2	52.5	60.3	69.5	75.8	77.4	85.4	91.1	96.1	68.3
2006	26.6	37.4	54.3	59.8	67.5	73.9	83.8	82.4	87.7	88.9	66.2
2007	35.3	45.5	53.1	60.2	65.6	71.7	83.2	87.1	87.2	97.1	68.6
2008	28.6	48.3	59.2	63.6	69.8	77.4	81.7	91.1	91.6	94.7	70.6
2009	38.9	46.7	56.5	65.9	70.2	75.4	81.2	86.1	99.3	100.7	72.1
2010	35.3	49.0	57.6	62.1	68.7	68.9	79.1	83.4	94.8	102.6	70.1
2011	30.1	45.8	54.4	62.3	69.4	74.5	73.3	83.3	98.5	95.8	68.7
2012	30.5	43.9	53.3	63.0	70.1	72.8	76.2	82.3	80.2	81.3	65.4
2013	31.3	45.2	55.5	63.5	70.7	77.2	81.0	83.5	92.0	88.6	68.9
2014	29.5	44.7	57.2	61.2	67.3	73.0	82.4	91.1	-	-	63.3
2015	33.7	46.7	55.9	66.0	70.6	75.7	87.4	106.4	98.5	82.0	72.3
2016	22.4	40.1	55.2	62.3	74.6	75.3	82.7	91.2	115.7	-	68.8
2017	25.0	45.1	54.7	63.3	75.5	83.3	86.0	87.1	103.0	-	69.2
Min	22.4	37.4	52.5	59.8	65.6	68.9	73.3	82.3	80.2	81.3	63.3
Max	43.7	53.9	61.5	72.0	80.4	88.8	100.4	106.4	115.7	114.3	79.3
Avg.[1]	27.1	44.0	55.3	63.9	73.6	78.1	85.4	94.9	105.7	82.0	70.1

[1]for 2015-2017

Table 6. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the DFO survey, 1986-2018.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1986	0	770	3538	3204	331	692	445	219	35	66	0	10	0	0	0	0	0	9311
1987	0	48	1791	642	753	162	89	181	89	13	13	0	13	16	0	0	0	3812
1988	0	148	450	5337	565	838	95	79	179	18	12	4	0	16	0	0	0	7741
1989	0	350	2169	764	1706	258	332	42	85	112	5	32	8	5	0	0	0	5868
1990	20.06	106	795	3471	1953	4402	535	1094	144	157	289	65	52	37	0	0	5	13125
1991	0	1198	1019	1408	1639	882	1195	148	249	38	45	30	12	5	8	0	0	7876
1992	0	48	2049	1221	409	643	451	300	93	38	0	3	3	18	0	0	0	5276
1993	0	31	355	1723	622	370	754	274	268	51	31	0	20	6	0	0	0	4504
1994	0	13	629	691	1289	477	182	363	84	119	12	0	0	0	8	5	0	3871
1995	0	32	187	1240	757	520	186	44	67	28	18	8	6	0	0	0	0	3093
1996	0	90	203	1744	4337	1432	1034	445	107	149	39	4	0	0	5	0	0	9590
1997	0	30	376	568	1325	1262	216	50	35	23	17	0	3	0	0	0	0	3905
1998	0	6	582	831	322	317	238	56	29	7	8	3	4	0	0	0	0	2402
1999	0	3	156	1298	1090	449	317	190	10	28	5	9	0	3	0	0	0	3561
2000	0	0	423	1294	4967	2157	1031	510	317	20	23	12	0	0	0	0	0	10754
2001	0	3	37	802	519	1391	645	334	224	225	36	24	7	0	0	0	0	4248
2002	0	0	118	477	2097	694	1283	458	188	63	76	7	0	0	0	0	0	5462
2003	0	0	8	200	510	867	194	219	69	12	0	0	0	0	0	0	0	2078
2004	0	427	40	246	381	422	353	59	108	25	5	0	3	0	0	0	0	2069
2005	0	25	1025	1398	7149	1766	816	743	60	87	8	4	0	0	0	0	0	13082
2006	0	0	41	1500	673	1779	757	217	216	83	34	10	15	0	0	0	0	5325
2007	0	18	130	549	2606	379	653	119	81	53	0	4	0	0	0	0	0	4591
2008	0	12	147	1027	755	2978	194	392	41	4	20	0	0	0	0	0	0	5569
2009	0	11	51	2487	2261	519	2955	0	82	0	0	0	18	0	0	0	0	8384
2010	0	5	92	956	4105	1781	703	1828	65	84	5	0	0	0	0	0	0	9623
2011	0	193	271	766	952	1324	256	67	112	14	8	2	0	0	0	0	0	3965
2012	0	9	149	327	315	195	158	7	18	4	0	0	0	0	0	0	0	1182
2013	0	0	431	3754	2173	285	81	52	10	0	0	0	0	0	0	0	0	6786
2014	0	76	9	360	538	169	35	0	27	0	0	0	0	0	0	0	0	1213
2015	0	0	476	152	598	439	97	7	0	0	0	0	0	0	0	0	0	1770
2016	0	8	197	1004	199	273	147	16	4	0	0	0	0	0	0	0	0	1845
2017	0	5	52	1660	5897	194	270	188	0	0	0	0	0	0	0	0	0	8266
2018	0	39	149	520	1060	1610	77	50	7	0	0	0	0	0	0	0	0	3512

Table 7. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS spring survey, 1970-2018. Conversion factors to account for vessel and trawl door changes have been applied. During 1973-1981 a Yankee 41 net was used rather than the standard Yankee 36 net.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1970	0	354	1115	302	610	73	263	48	0	71	24	0	48	0	0	0	0	2907
1971	0	185	716	503	119	326	124	257	227	40	40	79	0	0	0	0	0	2615
1972	56	1578	1856	2480	393	114	136	60	88	73	18	14	0	0	14	0	0	6879
1973	0	665	37880	5474	6109	567	467	413	0	163	231	0	0	0	95	0	0	52064
1974	0	461	5877	4030	759	2001	360	91	267	45	48	54	0	0	0	0	0	13991
1975	0	0	467	3061	4348	446	960	79	0	122	0	0	0	0	0	0	0	9483
1976	84	1733	1111	620	444	759	0	167	35	0	0	0	0	48	0	0	0	5001
1977	0	0	2358	736	354	307	334	22	35	0	0	0	0	0	0	0	0	4145
1978	373	187	0	2825	615	916	153	787	62	43	40	0	0	0	0	0	0	6001
1979	71	339	1332	122	1430	543	176	91	130	0	0	0	0	0	0	0	0	4234
1980	0	11	2251	2168	169	1984	410	78	48	31	0	47	0	0	0	0	0	7197
1981	283	1956	1311	2006	1093	43	453	197	59	0	0	0	0	0	0	0	0	7399
1982	44	455	6642	13614	12667	9406	0	3088	992	120	0	0	0	0	0	0	0	47027
1983	0	389	2017	3781	779	608	315	106	98	0	70	0	0	0	0	0	35	8197
1984	0	103	117	344	483	92	182	74	18	105	0	0	0	0	0	0	0	1518
1985	58	36	2032	633	1061	1518	328	217	213	83	116	34	23	0	0	0	0	6352
1986	97	619	339	1132	298	427	536	20	109	142	0	0	0	0	0	0	0	3719
1987	0	0	1194	247	568	0	152	148	30	54	0	0	0	0	0	0	0	2394
1988	138	320	243	2795	274	461	51	5	67	0	0	10	0	0	0	0	0	4364
1989	0	174	1238	338	1685	234	396	99	12	36	48	24	0	0	0	0	0	4284
1990	24	45	360	1687	586	634	152	164	19	0	0	24	0	0	0	0	0	3696
1991	217	725	620	514	903	460	382	44	17	0	24	53	0	0	0	0	0	3957
1992	0	81	666	349	103	261	152	159	27	52	0	0	0	0	0	0	0	1850
1993	0	0	462	1284	262	46	182	46	43	46	12	0	0	0	0	0	0	2382
1994	38	54	194	152	185	44	11	33	0	8	0	0	0	0	0	0	0	720
1995	384	70	294	927	495	932	191	253	0	68	0	0	0	0	0	0	0	3614
1996	0	139	300	990	1343	121	94	28	0	0	0	0	0	0	0	0	0	3016
1997	271	54	218	48	402	519	53	126	57	0	0	0	0	0	0	0	0	1747
1998	54	0	1040	1985	995	983	609	30	31	0	0	0	0	0	0	0	0	5729
1999	22	22	145	673	624	370	172	107	34	8	0	0	0	0	0	0	0	2176
2000	36	0	304	643	1348	492	138	52	20	0	0	0	0	0	0	0	0	3032
2001	0	0	64	889	96	350	109	0	12	10	0	0	0	0	0	0	0	1530
2002	36	0	121	470	1081	175	214	61	0	0	0	0	0	0	0	0	0	2158
2003	0	0	125	287	812	1154	135	78	9	0	0	0	0	0	0	0	0	2599
2004	0	549	10	838	2091	2105	1351	239	382	29	0	0	0	0	0	0	0	7595
2005	36	15	345	70	747	287	190	131	34	0	0	0	0	0	0	0	0	1855
2006	0	37	73	952	411	1007	340	151	79	0	0	0	0	0	0	0	0	3050
2007	0	0	369	308	2258	239	291	47	28	0	0	0	0	0	0	0	0	3540
2008	43	37	112	675	372	1385	51	66	0	0	0	0	0	0	0	0	0	2741
2009	0	61	86	875	408	219	377	24	12	15	0	0	0	0	0	0	0	2078
2010	0	25	126	367	667	168	44	147	0	12	0	0	0	0	0	0	0	1556
2011	0	88	164	164	266	144	56	9	24	0	0	0	0	0	0	0	0	914
2012	3	3	450	749	834	209	127	13	0	0	0	0	0	0	0	0	0	2389
2013	0	0	653	3864	1202	129	64	15	0	0	0	0	0	0	0	0	0	5926
2014	0	55	64	568	922	109	27	0	0	0	0	0	0	0	0	0	0	1746
2015	0	9	165	71	222	331	23	0	0	0	0	0	0	0	0	0	0	820
2016	4	4	179	1,454	173	168	82	10	0	0	0	0	0	0	0	0	0	2074
2017	0	43	54	469	2681	808	502	165	0	0	0	0	0	0	0	0	0	4274
2018	0	99	149	607	550	346	0	0	0	18	0	0	0	0	0	0	0	1770

Table 8. Indices of swept area abundance (thousands) for eastern Georges Bank cod from the NMFS fall survey, 1970-2017. Conversion factors to account for vessel and trawl door changes have been applied.

Year/Age	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16+	Total
1970	348	1416	836	208	412	11	0	0	5	25	0	0	0	0	0	0	0	3261
1971	203	1148	900	181	232	130	142	14	0	0	0	0	0	0	0	0	0	2951
1972	1110	3299	614	667	24	40	0	0	0	0	0	0	0	0	0	0	0	5753
1973	46	2435	2947	997	979	93	0	25	63	0	0	0	0	0	0	0	0	7584
1974	77	196	399	622	54	31	15	0	0	0	0	0	0	0	0	0	0	1394
1975	414	660	177	414	764	27	46	0	0	0	0	0	0	0	0	0	0	2501
1976	0	8260	362	144	0	91	0	48	0	0	0	0	0	0	0	0	0	8904
1977	51	0	3475	714	184	156	178	3	0	0	0	0	0	0	0	0	0	4760
1978	113	1519	58	3027	417	58	63	77	0	0	0	0	0	0	0	0	0	5330
1979	182	1704	1695	116	1522	243	48	20	11	18	0	0	0	0	0	0	0	5557
1980	315	782	409	649	22	184	14	17	20	0	0	0	0	0	0	0	0	2412
1981	360	2352	1208	933	269	15	29	0	0	0	53	0	0	0	0	0	0	5220
1982	0	549	718	54	59	0	0	27	0	0	0	0	0	0	0	0	0	1406
1983	948	73	267	567	24	8	8	0	23	0	0	0	0	0	0	0	0	1917
1984	29	1805	120	690	1025	23	32	0	0	9	0	0	0	0	0	0	0	3734
1985	1245	209	993	161	18	5	9	0	0	0	4	0	0	0	0	0	0	2645
1986	119	3018	56	198	0	0	6	0	0	0	0	0	0	0	0	0	0	3396
1987	156	129	845	121	100	0	0	0	0	0	0	0	7	0	0	0	0	1357
1988	95	561	177	1182	163	206	0	30	41	10	0	0	0	0	0	0	0	2464
1989	318	570	1335	222	607	78	24	0	0	0	0	0	0	0	0	0	0	3154
1990	198	403	442	831	120	204	20	0	15	0	0	0	0	0	0	0	0	2232
1991	0	158	60	71	10	24	0	0	0	0	0	0	0	0	0	0	0	322
1992	0	205	726	154	0	37	12	0	0	0	0	0	0	0	0	0	0	1134
1993	0	81	104	158	19	0	0	0	0	0	0	0	0	0	0	0	0	362
1994	10	78	282	220	143	13	26	0	0	0	0	0	0	0	0	0	0	771
1995	223	28	122	304	66	29	7	0	0	0	0	0	0	0	0	0	0	779
1996	10	291	76	293	211	53	28	0	0	0	0	0	0	0	0	0	0	961
1997	0	161	394	181	58	84	29	0	0	0	0	0	0	0	0	0	0	907
1998	0	171	684	480	65	109	0	0	29	0	0	0	0	0	0	0	0	1538
1999	0	15	14	249	124	32	0	0	0	0	0	0	0	0	0	0	0	434
2000	30	55	204	68	89	46	0	0	0	0	0	0	0	0	0	0	0	493
2001	25	74	106	257	38	75	12	12	0	0	0	0	0	0	0	0	0	598
2002	122	110	635	712	2499	170	211	17	0	0	0	0	0	0	0	0	0	4476
2003	76	0	24	100	70	17	0	6	0	0	0	0	0	0	0	0	0	293
2004	108	422	68	840	385	545	436	103	30	0	30	0	0	0	0	0	0	2969
2005	21	29	508	114	251	43	0	10	0	0	0	0	0	0	0	0	0	976
2006	0	146	123	530	37	263	16	16	16	16	0	0	0	0	0	0	0	1162
2007	60	22	136	7	69	0	7	0	0	0	0	0	0	0	0	0	0	302
2008	0	74	170	55	15	98	15	15	0	0	0	0	0	0	0	0	0	442
2009	54	37	194	280	39	18	11	0	0	0	0	0	0	0	0	0	0	633
2010	434	27	79	74	121	20	0	0	0	0	0	0	0	0	0	0	0	755
2011	58	323	362	248	177	110	32	0	0	0	0	0	0	0	0	0	0	1309
2012	0	14	188	90	13	20	0	0	0	0	0	0	0	0	0	0	0	324
2013	162	51	565	554	226	0	0	0	0	0	0	0	0	0	0	0	0	1559
2014	98	144	47	145	223	28	14	0	0	0	0	0	0	0	0	0	0	697
2015	42	223	1208	94	162	131	0	0	0	0	0	0	0	0	0	0	0	1859
2016	2	9	219	2123	50	143	51	0	0	0	0	0	0	0	0	0	0	2597
2017	43	73	76	66	91	0	0	0	0	0	0	0	0	0	0	0	0	348

Table 9. Mean weight and number per tow indices for each survey with accompanying CVs. Conversion factors to account for vessel and trawl door changes in the NMFS surveys have been applied.

Year	DFO N/Tow		DFO Kg/Tow		NMFS Spring N/Tow		NMFS Spring Kg/Tow		NMFS Fall N/Tow		NMFS Fall Kg/Tow	
	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV	Mean	CV
1970	-	-	-	-	5.59	0.38	6.16	0.43	5.88	0.22	9.12	0.23
1971	-	-	-	-	4.72	0.26	7.73	0.42	5.32	0.37	9.54	0.30
1972	-	-	-	-	12.41	0.19	10.21	0.22	10.38	0.59	7.12	0.40
1973	-	-	-	-	93.92	0.64	61.01	0.55	14.29	0.33	22.04	0.45
1974	-	-	-	-	25.24	0.28	20.21	0.28	2.68	0.41	5.27	0.42
1975	-	-	-	-	17.11	0.17	24.23	0.16	4.51	0.41	9.46	0.44
1976	-	-	-	-	9.62	0.25	8.18	0.23	17.12	0.44	9.77	0.32
1977	-	-	-	-	7.48	0.15	6.92	0.22	8.59	0.19	17.15	0.17
1978	-	-	-	-	10.82	0.26	16.85	0.27	9.62	0.24	22.03	0.24
1979	-	-	-	-	7.64	0.21	9.51	0.22	10.02	0.32	23.54	0.25
1980	-	-	-	-	13.84	0.37	16.21	0.32	4.36	0.27	8.11	0.28
1981	-	-	-	-	13.78	0.22	22.77	0.18	9.42	0.26	13.09	0.26
1982	-	-	-	-	84.83	0.83	204.64	0.89	2.54	0.52	4.00	0.41
1983	-	-	-	-	14.79	0.13	15.10	0.24	3.46	0.29	4.42	0.43
1984	-	-	-	-	2.92	0.20	3.80	0.22	6.74	0.43	12.66	0.64
1985	-	-	-	-	11.46	0.35	41.83	0.27	4.77	0.53	4.31	0.83
1986	21.54	-	-	-	6.71	0.21	22.61	0.28	6.13	0.57	3.92	0.47
1987	9.18	0.42	21.25	0.35	4.32	0.23	13.74	0.25	2.45	0.47	4.75	0.47
1988	18.64	0.33	46.84	0.30	7.87	0.34	16.77	0.34	4.44	0.36	12.20	0.45
1989	14.13	0.16	35.03	0.19	7.73	0.32	34.98	0.30	5.69	0.42	9.28	0.42
1990	31.60	0.18	136.44	0.26	6.89	0.42	32.32	0.30	4.03	0.58	9.24	0.70
1991	18.96	0.16	60.36	0.16	7.14	0.15	27.14	0.17	0.72	0.55	0.97	0.53
1992	12.70	0.17	35.11	0.27	3.34	0.22	11.03	0.20	2.05	0.41	3.13	0.46
1993	10.84	0.21	39.84	0.21	4.30	0.41	11.90	0.31	0.65	0.48	1.09	0.58
1994	9.32	0.32	31.64	0.50	1.38	0.37	3.98	0.31	1.44	0.68	3.23	0.82
1995	7.45	0.34	19.55	0.34	6.52	0.36	18.24	0.49	1.41	0.47	2.20	0.62
1996	23.09	0.24	77.47	0.30	5.44	0.39	11.93	0.42	1.85	0.47	3.44	0.43
1997	9.40	0.25	26.50	0.25	3.15	0.28	7.31	0.22	1.64	0.88	3.38	0.96
1998	5.78	0.19	12.05	0.22	11.01	0.46	23.58	0.47	2.90	0.35	5.60	0.28
1999	8.57	0.24	22.10	0.35	3.92	0.21	9.57	0.24	0.78	0.74	1.88	0.66
2000	25.89	0.55	77.77	0.45	5.47	0.28	13.30	0.27	0.89	0.41	1.62	0.35
2001	10.23	0.37	43.43	0.44	2.76	0.44	6.71	0.45	1.08	0.45	2.09	0.58
2002	13.15	0.31	48.96	0.42	4.15	0.32	8.52	0.26	8.07	0.54	20.79	0.67
2003	5.00	0.15	14.97	0.17	4.69	0.48	18.51	0.54	0.53	0.36	1.10	0.45
2004	4.98	0.20	13.63	0.29	13.70	0.54	38.02	0.62	5.36	0.59	15.06	0.78
2005	31.50	0.66	63.09	0.59	3.35	0.24	7.95	0.24	1.76	0.44	2.61	0.44
2006	12.82	0.27	30.21	0.28	5.50	0.26	13.22	0.27	2.23	0.66	4.16	0.79
2007	11.05	0.21	27.03	0.26	6.39	0.29	10.94	0.28	0.54	0.33	0.77	0.38
2008	13.41	0.27	32.88	0.28	4.94	0.26	9.61	0.26	0.80	0.27	1.43	0.30
2009	20.19	0.58	55.81	0.67	3.75	0.36	7.83	0.31	1.14	0.45	2.17	0.39
2010	23.17	0.59	63.45	0.65	2.81	0.20	6.47	0.22	1.36	0.77	1.32	0.40
2011	9.55	0.22	20.31	0.25	1.76	0.29	3.32	0.35	2.36	0.52	4.16	0.70
2012	2.85	0.18	5.90	0.21	4.31	0.30	8.77	0.26	0.60	0.46	1.10	0.39
2013	16.34	0.43	26.76	0.49	10.69	0.62	17.35	0.62	2.81	0.58	4.63	0.65
2014	2.92	0.22	5.80	0.27	3.17	0.32	5.87	0.31	1.26	0.53	2.48	0.51
2015	4.26	0.33	8.65	0.38	1.48	0.20	3.15	0.22	3.35	0.41	6.44	0.40
2016	4.45	0.21	8.80	0.23	3.74	0.67	6.46	0.57	4.69	0.31	9.81	0.33
2017	19.90	0.68	35.07	0.60	8.52	0.39	24.31	0.49	0.67	0.81	1.25	0.69
2018	8.46	0.35	17.33	0.37	3.40	0.61	5.95	0.66	-	-	-	-

Table 10.Swept area biomass (mt) for eastern Georges Bank cod from the DFO, NMFS spring and fall surveys. Conversion factors to account for vessel and trawl door changes have been applied. The biomass conversion factor used for the Henry B. Bigelow since 2009 is 1.58 ($B_{survey}=B_{bigelow}/1.58$).

Year	NMFS Fall	NMFS spring	DFO
1970	5,054	7,801	-
1971	5,287	10,435	-
1972	3,947	13,779	-
1973	11,697	82,311	-
1974	2,741	27,269	-
1975	5,246	23,503	-
1976	5,082	10,354	-
1977	9,509	9,335	-
1978	12,213	22,731	-
1979	13,050	12,831	-
1980	4,494	20,520	-
1981	7,256	18,568	-
1982	2,216	172,300	-
1983	2,449	20,376	-
1984	7,018	4,808	-
1985	2,390	23,190	-
1986	2,174	12,532	18,633
1987	2,634	7,615	8,824
1988	6,764	9,294	19,452
1989	5,145	12,104	14,547
1990	5,121	10,828	56,665
1991	435	9,391	25,068
1992	1,734	6,113	14,581
1993	606	6,598	16,545
1994	1,734	1,294	13,140
1995	1,220	10,113	8,118
1996	1,790	6,613	32,173
1997	1,875	4,051	11,004
1998	2,970	12,267	5,006
1999	1,044	5,308	9,178
2000	895	7,374	32,298
2001	1,159	3,721	18,037
2002	11,525	4,432	20,333
2003	608	6,405	6,218
2004	8,347	21,080	5,661
2005	1,446	4,407	26,200
2006	2,165	7,331	12,546
2007	424	6,066	11,228
2008	792	5,327	13,657
2009	1,203	4,343	23,180
2010	732	3,587	26,352
2011	2,304	1,724	8,437
2012	609	4,864	2,449
2013	2,566	9,616	11,113
2014	1,376	3,254	2,409
2015	3,570	1,748	3,594
2016	5,438	3,579	3,656
2017	653	13,479	14,566
2018	-	3,097	7,198

Table 11. Beginning of year population weights at age (kg) derived from DFO and NMFS spring surveys. The weight at age for age group 10+ was derived from catch number weighted fishery weight at age.

Year/Age	1	2	3	4	5	6	7	8	9	10+
1970	0.093	0.838	1.735	2.597	4.797	5.644	8.153	7.990	11.427	14.635
1971	0.116	0.811	1.798	2.347	4.372	5.377	6.450	7.990	7.384	14.635
1972	0.085	0.866	1.979	2.959	3.482	5.212	5.608	6.539	13.806	14.635
1973	0.085	0.802	1.890	2.958	3.247	3.434	7.722	7.129	9.998	14.635
1974	0.149	0.606	1.705	2.641	4.173	5.806	7.452	7.754	8.153	14.635
1975	0.109	1.132	2.354	2.745	3.734	5.184	7.714	7.567	9.150	14.635
1976	0.138	0.946	2.156	2.999	3.753	5.342	8.011	7.384	9.150	14.635
1977	0.124	0.905	2.130	3.365	6.182	5.503	6.667	5.664	9.150	14.635
1978	0.112	0.886	1.624	3.564	5.414	6.247	8.626	8.973	10.226	14.635
1979	0.112	0.868	1.740	2.995	4.565	5.188	9.629	10.885	10.976	14.635
1980	0.276	0.706	1.892	2.786	5.244	6.281	5.919	8.973	11.762	14.635
1981	0.095	0.852	1.826	3.342	4.971	6.862	8.184	12.712	11.262	14.635
1982	0.092	0.869	2.219	3.050	4.114	6.427	8.061	8.828	10.776	14.635
1983	0.224	1.131	1.871	2.263	3.132	6.011	8.153	8.653	10.525	14.635
1984	0.050	0.582	1.954	2.443	2.699	4.121	5.890	8.973	10.279	14.635
1985	0.087	0.646	1.926	3.205	3.781	5.834	8.771	9.866	14.114	14.635
1986	0.131	0.770	1.742	3.217	4.920	5.698	7.439	8.988	10.684	14.635
1987	0.150	0.845	1.701	2.686	5.672	7.487	7.480	6.659	10.100	14.635
1988	0.152	0.931	1.785	3.020	4.169	6.268	8.438	8.724	12.330	14.635
1989	0.142	0.832	1.705	2.759	4.306	6.432	7.615	7.813	11.320	14.635
1990	0.215	0.787	1.843	2.899	4.362	6.003	8.589	9.518	13.493	14.635
1991	0.088	0.897	1.952	3.167	4.243	4.895	7.544	10.059	9.973	14.635
1992	0.127	0.846	2.045	2.793	4.163	6.127	6.979	8.555	10.448	14.635
1993	0.070	0.955	1.845	2.907	4.513	5.889	6.999	7.383	9.341	14.635
1994	0.143	0.657	1.433	2.629	3.954	7.458	7.330	8.661	9.211	14.635
1995	0.183	0.794	1.587	2.245	3.474	4.697	6.692	7.920	11.833	14.635
1996	0.088	0.838	1.553	2.597	3.908	6.112	5.458	12.028	11.920	14.635
1997	0.190	0.717	1.694	2.176	3.218	6.200	6.204	9.796	10.174	14.635
1998	0.078	0.650	1.382	2.258	3.034	4.516	5.831	7.787	8.211	14.635
1999	0.111	1.001	1.350	2.237	2.973	4.635	6.513	8.250	8.568	14.635
2000	0.060	0.896	1.587	2.326	3.234	4.461	6.501	8.211	11.523	14.635
2001	0.010	0.771	1.418	2.584	3.602	5.089	6.909	7.552	10.089	11.607
2002	0.016	0.495	1.214	2.269	3.538	4.385	5.856	8.436	10.001	11.607
2003	0.016	0.441	1.141	1.882	3.046	3.361	5.120	6.702	7.661	11.607
2004	0.022	0.288	1.454	2.447	3.449	4.086	4.312	6.320	9.923	11.607
2005	0.058	0.589	1.167	1.770	2.972	3.297	3.936	7.655	6.448	11.607
2006	0.031	0.307	1.151	1.574	2.621	3.182	4.615	4.684	5.729	11.607
2007	0.054	0.625	1.073	1.764	2.622	4.098	5.789	6.810	7.981	11.607
2008	0.046	0.577	1.450	2.041	2.504	3.465	4.165	7.931	10.050	11.607
2009	0.114	0.724	1.470	2.482	2.701	3.527	4.479	5.594	8.285	11.607
2010	0.079	0.657	1.575	2.214	3.194	3.501	3.963	5.380	6.520	11.607
2011	0.038	0.482	1.193	2.036	2.709	3.581	3.670	4.484	5.080	11.607
2012	0.020	0.508	1.189	2.158	2.907	3.760	5.106	6.329	5.300	11.607
2013	0.029	0.685	1.216	2.016	2.785	3.557	4.343	5.350	7.047	11.607
2014	0.079	0.565	1.243	1.821	3.116	4.745	4.724	6.580	7.050	11.607
2015	0.043	0.493	1.124	2.352	2.813	3.586	5.620	6.086	7.050	11.607
2016	0.132	0.912	1.157	2.157	3.163	4.334	4.997	6.005	7.050	11.607
2017	0.067	0.545	1.238	2.070	3.166	4.237	4.510	6.224	7.050	11.607
2018	0.137	0.623	1.244	1.752	2.497	3.479	5.144	4.875	4.690	11.607
Average	0.098	0.738	1.606	2.522	3.698	4.992	6.406	7.758	9.393	13.523
Minimum	0.010	0.288	1.073	1.574	2.497	3.182	3.670	4.484	4.690	11.607
Maximum	0.276	1.132	2.354	3.564	6.182	7.487	9.629	12.712	14.114	14.635

Table 12. Statistical properties of estimates for population abundance (numbers in thousands) for age 9 in 2014 (row number 1), beginning of year population estimates for 2018 (row numbers 2 to 9) and survey catchability (dimensionless, row numbers 10 to 38) from the "M 0.8" benchmark model formulation for eastern Georges Bank cod obtained from a bootstrap with 5000 replications.

Row Number	Parameter	Estimate (thousands)	Standard Error	Relative Error	Relative Bias
1	N[2014 9]	58	16	28%	3%
2	N[2018 2]	994	630	63%	14%
3	N[2018 3]	369	173	47%	9%
4	N[2018 4]	1148	501	44%	8%
5	N[2018 5]	1868	649	35%	5%
6	N[2018 6]	186	76	41%	7%
7	N[2018 7]	170	59	34%	5%
8	N[2018 8]	249	70	28%	3%
9	N[2018 9]	24	9	36%	5%
10	DFO age 1	0.01	0.003	22%	2%
11	DFO age 2	0.12	0.02	20%	2%
12	DFO age 3	0.62	0.12	20%	2%
13	DFO age 4	1.05	0.21	20%	2%
14	DFO age 5	1.15	0.23	20%	2%
15	DFO age 6	1.06	0.21	20%	2%
16	DFO age 7	1.00	0.21	21%	2%
17	DFO age 8	1.31	0.28	21%	2%
18	NMFS Spring Y41 age 1	0.02	0.01	70%	16%
19	NMFS Spring Y41 age 2	0.19	0.18	92%	25%
20	NMFS Spring Y41 age 3	0.22	0.16	73%	17%
21	NMFS Spring Y41 age 4	0.21	0.14	69%	16%
22	NMFS Spring Y41 age 5	0.31	0.22	73%	17%
23	NMFS Spring Y41 age 6	0.30	0.21	73%	18%
24	NMFS Spring Y41 age 7	0.38	0.27	71%	17%
25	NMFS Spring Y41 age 8	0.33	0.23	70%	17%
26	NMFS Spring Y36 age 1	0.02	0.01	22%	2%
27	NMFS Spring Y36 age 2	0.12	0.02	19%	1%
28	NMFS Spring Y36 age 3	0.38	0.07	19%	2%
29	NMFS Spring Y36 age 4	0.59	0.11	19%	2%
30	NMFS Spring Y36 age 5	0.59	0.11	19%	1%
31	NMFS Spring Y36 age 6	0.50	0.10	20%	2%
32	NMFS Spring Y36 age 7	0.45	0.09	20%	2%
33	NMFS Spring Y36 age 8	0.46	0.11	24%	3%
34	NMFS Fall age 1	0.05	0.01	19%	1%
35	NMFS Fall age 2	0.10	0.02	18%	1%
36	NMFS Fall age 3	0.15	0.03	18%	1%
37	NMFS Fall age 4	0.11	0.02	19%	1%
38	NMFS Fall age 5	0.09	0.02	20%	2%

Table 13. Mohn's rho values for Age-1 recruitment, SSB, and F with 5-year peels for the VPA "M 0.8" model.

Peel	Age 1	3+ Biomass	F
1	-0.44	0.20	0.15
2	0.41	-0.02	0.10
3	-0.26	0.27	-0.20
4	-0.44	0.77	-0.70
5	-0.30	1.20	-0.82
Mohn's Rho	-0.21	0.48	-0.30

Table 14. Beginning of year population biomass (mt) for eastern Georges Bank cod during 1978-2018 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2018. The dash (-) at age 1 in 2018 indicates that age 1 in the final year is not estimated in the model.

Year	Age											
	1	2	3	4	5	6	7	8	9	10+	1+	3+
1978	1391	2962	17458	14216	7106	4461	5335	946	1135	1463	56474	52120
1979	1174	8843	4591	16585	10125	3742	4220	4264	729	2098	56371	46354
1980	2778	6032	14275	4181	16615	8341	2526	2623	3132	2289	62791	53981
1981	1654	7011	11170	15681	4761	11839	6296	3330	2431	4181	68355	59691
1982	524	12411	13223	10171	10866	3433	7952	4124	1382	4906	68992	56057
1983	1144	5256	15969	7040	4992	7152	2137	3897	2561	4256	54402	48002
1984	719	2420	6058	11564	3744	3299	3635	981	2117	4143	38680	35541
1985	460	7538	6160	5816	10057	3773	2802	2528	774	3778	43684	35686
1986	3159	3318	12154	4374	4397	7369	2139	1462	1188	2994	42556	36079
1987	1236	16625	5311	9885	3332	3178	4866	1161	912	3244	49751	31889
1988	2151	6259	22147	5425	8270	2095	1932	3282	1311	3270	56142	47732
1989	730	9607	8945	17660	3710	5528	1198	653	1648	2770	52450	42113
1990	1598	3295	16295	10334	15100	3005	3177	745	444	2888	56881	51988
1991	847	5454	5410	14103	8430	7855	2107	1671	529	2203	48609	42309
1992	463	6635	8359	3818	8006	5021	4520	1153	774	1810	40557	33460
1993	331	2791	7574	6134	3189	4598	2729	1840	652	1772	31609	28488
1994	507	2528	2784	4391	3617	2321	2335	1733	1081	1703	22999	19964
1995	381	2301	4741	2597	2306	2379	744	824	838	1318	18428	15746
1996	313	1430	3604	5796	3369	2744	1177	546	526	1021	20525	18782
1997	1062	2094	2305	3676	4729	3933	1010	863	183	717	20574	17417
1998	168	2971	3122	2099	3219	3980	1349	384	256	391	17938	14799
1999	533	1764	4927	3505	1832	3366	2017	737	118	323	19122	16825
2000	112	3519	2177	5940	3168	1811	1867	844	359	205	20002	16371
2001	12	1172	4479	2644	6295	3391	1094	865	386	210	20548	19364
2002	36	472	1393	4824	2294	4703	1359	428	403	235	16148	15640
2003	9	814	882	1556	4079	1456	1955	569	132	250	11703	10880
2004	83	129	2153	1221	1583	2994	615	727	260	160	9925	9713
2005	33	1844	416	1923	812	803	947	319	210	143	7451	5574
2006	81	143	2879	395	1856	569	405	401	70	183	6981	6757
2007	64	1343	392	3252	355	1658	291	191	218	113	7876	6470
2008	23	564	2479	497	2832	279	532	121	81	140	7547	6960
2009	40	292	1117	3158	391	2477	119	203	35	82	7915	7582
2010	91	186	459	980	2926	271	904	33	63	44	5958	5681
2011	152	454	230	314	473	2447	93	360	5	56	4584	3978
2012	29	1654	870	194	128	155	1480	25	166	27	4729	3045
2013	19	802	3168	1016	82	37	16	675	9	170	5993	5172
2014	348	303	1161	3701	1140	69	3	5	398	82	7210	6558
2015	87	1769	477	1623	4419	984	23	1	2	331	9716	7860
2016	69	1503	3327	675	1584	5391	597	9	0	147	13303	11731
2017	70	231	1653	4692	705	1617	2460	324	4	67	11822	11520
2018	-	531	418	1848	4428	604	831	1179	162	33	10032	9502

Table 15. Beginning of year population abundance (numbers in thousands) for eastern Georges Bank cod during 1978-2018 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2018. The dash (-) at age 1 in 2018 indicates that age 1 in the final year is not estimated in the model.

Year	Age										
	1	2	3	4	5	6	7	8	9	10+	1+
1978	12459	3342	10752	3989	1312	714	618	105	111	100	33504
1979	10450	10193	2639	5537	2218	721	438	392	66	143	32798
1980	10052	8542	7543	1501	3169	1328	427	292	266	156	33276
1981	17481	8224	6117	4692	958	1725	769	262	216	286	40731
1982	5693	14281	5958	3334	2641	534	986	467	128	335	34359
1983	5107	4648	8533	3111	1594	1190	262	450	243	291	25428
1984	14264	4161	3100	4733	1387	801	617	109	206	283	29661
1985	5273	11663	3199	1815	2660	647	319	256	55	258	26144
1986	24076	4309	6978	1360	894	1293	288	163	111	205	39675
1987	8240	19674	3122	3681	587	424	651	174	90	222	36865
1988	14131	6726	12406	1796	1984	334	229	376	106	223	38311
1989	5131	11549	5246	6401	862	859	157	84	146	189	30624
1990	7446	4184	8842	3565	3462	501	370	78	33	197	28677
1991	9647	6082	2772	4453	1987	1605	279	166	53	151	27195
1992	3645	7841	4087	1367	1923	819	648	135	74	124	20662
1993	4713	2923	4106	2110	707	781	390	249	70	121	16169
1994	3546	3849	1943	1670	915	311	319	200	117	116	12987
1995	2085	2898	2987	1156	664	507	111	104	71	90	10673
1996	3575	1706	2321	2232	862	449	216	45	44	70	11520
1997	5593	2922	1361	1689	1470	634	163	88	18	49	13987
1998	2159	4571	2259	930	1061	881	231	49	31	27	12199
1999	4809	1762	3651	1567	616	726	310	89	14	22	13566
2000	1860	3929	1372	2553	980	406	287	103	31	14	11536
2001	1170	1520	3159	1023	1748	666	158	115	38	18	9616
2002	2258	955	1148	2126	648	1073	232	51	40	20	8551
2003	549	1848	773	827	1339	433	382	85	17	22	6274
2004	3851	449	1481	499	459	733	143	115	26	14	7769
2005	574	3132	357	1086	273	244	241	42	33	12	5994
2006	2626	467	2501	251	708	179	88	86	12	16	6933
2007	1196	2147	365	1844	136	404	50	28	27	10	6208
2008	495	977	1710	244	1131	80	128	15	8	12	4800
2009	354	404	760	1272	145	702	27	36	4	7	3711
2010	1153	283	291	443	916	77	228	6	10	4	3412
2011	3989	942	193	154	174	683	25	80	1	5	6247
2012	1432	3258	732	90	44	41	290	4	31	2	5924
2013	656	1170	2606	504	30	10	4	126	1	15	5122
2014	4387	536	934	2032	366	15	1	1	56	7	8335
2015	2013	3588	424	690	1571	274	4	0	0	29	8595
2016	522	1648	2877	313	501	1244	119	2	0	13	7239
2017	1040	424	1335	2266	223	382	545	52	1	6	6274
2018	-	851	336	1055	1773	174	162	242	23	3	4618

Table 16. Annual fishing mortality rate for eastern Georges Bank cod during 1978-2017 from the "M 0.8" model formulation using the bootstrap bias adjusted population abundance at the beginning of 2018.

Year	Age										
	1	2	3	4	5	6	7	8	9	10+	F4-9
1978	0.00	0.04	0.46	0.39	0.40	0.29	0.26	0.26	0.26	0.11	0.36
1979	0.00	0.10	0.36	0.36	0.31	0.32	0.20	0.19	0.20	0.05	0.33
1980	0.00	0.13	0.27	0.25	0.41	0.35	0.29	0.10	0.21	0.16	0.33
1981	0.00	0.12	0.41	0.37	0.38	0.36	0.30	0.51	0.35	0.10	0.37
1982	0.00	0.32	0.45	0.54	0.60	0.51	0.58	0.45	0.54	0.18	0.56
1983	0.00	0.20	0.39	0.61	0.49	0.46	0.67	0.58	0.62	0.30	0.55
1984	0.00	0.06	0.34	0.38	0.56	0.72	0.68	0.49	0.65	0.31	0.48
1985	0.00	0.31	0.66	0.51	0.52	0.61	0.47	0.63	0.55	0.17	0.53
1986	0.00	0.12	0.44	0.64	0.54	0.49	0.30	0.39	0.33	0.07	0.53
1987	0.00	0.26	0.35	0.42	0.36	0.42	0.35	0.29	0.34	0.06	0.40
1988	0.00	0.05	0.46	0.53	0.64	0.55	0.81	0.75	0.77	0.20	0.61
1989	0.00	0.07	0.19	0.41	0.34	0.64	0.50	0.73	0.58	0.17	0.44
1990	0.00	0.21	0.49	0.38	0.57	0.38	0.60	0.19	0.53	0.18	0.47
1991	0.01	0.20	0.51	0.64	0.69	0.71	0.53	0.61	0.56	0.22	0.66
1992	0.02	0.45	0.46	0.46	0.70	0.54	0.75	0.46	0.70	0.11	0.61
1993	0.00	0.21	0.70	0.64	0.62	0.70	0.47	0.55	0.50	0.19	0.62
1994	0.00	0.05	0.32	0.72	0.39	0.23	0.32	0.24	0.29	0.03	0.52
1995	0.00	0.02	0.09	0.09	0.19	0.05	0.10	0.06	0.08	0.00	0.11
1996	0.00	0.03	0.12	0.22	0.11	0.21	0.09	0.12	0.10	0.01	0.18
1997	0.00	0.06	0.18	0.26	0.31	0.21	0.39	0.24	0.34	0.05	0.28
1998	0.00	0.02	0.17	0.21	0.18	0.25	0.15	0.48	0.21	0.12	0.21
1999	0.00	0.05	0.16	0.27	0.22	0.13	0.30	0.25	0.29	0.05	0.23
2000	0.00	0.02	0.09	0.18	0.19	0.14	0.12	0.19	0.14	0.07	0.17
2001	0.00	0.08	0.20	0.26	0.29	0.25	0.34	0.24	0.30	0.09	0.27
2002	0.00	0.01	0.13	0.26	0.20	0.23	0.21	0.28	0.22	0.26	0.24
2003	0.00	0.02	0.24	0.39	0.40	0.31	0.40	0.38	0.40	0.12	0.39
2004	0.01	0.03	0.11	0.40	0.43	0.31	0.43	0.46	0.44	0.25	0.38
2005	0.01	0.03	0.15	0.23	0.22	0.22	0.23	0.43	0.26	0.21	0.23
2006	0.00	0.05	0.10	0.42	0.36	0.47	0.34	0.34	0.34	0.20	0.38
2007	0.00	0.03	0.21	0.29	0.32	0.35	0.39	0.45	0.41	0.09	0.30
2008	0.00	0.05	0.09	0.32	0.27	0.30	0.46	0.48	0.46	0.12	0.30
2009	0.02	0.13	0.34	0.12	0.43	0.32	0.66	0.51	0.57	0.14	0.22
2010	0.00	0.19	0.44	0.73	0.09	0.31	0.24	0.94	0.25	0.14	0.29
2011	0.00	0.05	0.56	1.06	1.24	0.05	1.03	0.13	0.34	0.07	0.41
2012	0.00	0.02	0.16	0.91	1.25	1.61	0.03	0.36	0.03	0.01	0.43
2013	0.00	0.02	0.05	0.11	0.50	1.84	0.88	0.01	0.03	0.007	0.14
2014	0.00	0.03	0.10	0.05	0.08	0.46	0.65	0.25	0.00	0.00	0.06
2015	0.00	0.02	0.10	0.11	0.03	0.03	0.19	0.27	0.20	0.01	0.05
2016	0.01	0.01	0.03	0.13	0.07	0.02	0.03	0.18	0.03	0.00	0.05
2017	0.00	0.03	0.03	0.04	0.04	0.05	0.01	0.02	0.01	0.00	0.04

Table 17. Projection inputs for eastern Georges Bank cod.

Parameter	Age									
	1	2	3	4	5	6	7	8	9	10+
Natural Mortality										
2018-2020	0.2	0.2	0.2	0.2	0.2	0.8	0.8	0.8	0.8	0.8
Fishery Partial Recruitment (" M 0.8" model, avg 2013-2017)										
2018-2020	0.02	0.29	0.74	1.00	0.78	0.66	0.33	0.17	0.02	0.12
Fishery Partial Recruitment – Sensitivity Flat Top (avg 1994-2012)										
2018-2020	0.01	0.12	0.55	1.00	0.95	0.79	0.89	0.96	0.81	0.23
Fishery Weight at Age										
2018-2020	0.25	0.99	1.86	2.84	4.42	5.33	6.82	9.32	12.26	11.61
Population Beginning of Year Weight at Age										
2018	0.14	0.62	1.24	1.75	2.50	3.48	5.14	4.88	7.05	11.61
2019-2021	0.11	0.69	1.21	1.99	2.94	4.02	4.88	5.70	7.05	11.61

Table 18. Deterministic projection results for eastern Georges Bank cod based on F reference point 0.11 from the "M 0.8" model. Shaded values are the 2010 year class (dark grey cells) and the 2013 year class (light grey cells). Bolded values show the year classes with assumed recruitments. A dash (-) indicates that this value was not calculated.

Parameter	Age												
	1	2	3	4	5	6	7	8	9	10+	1+	3+	4+
Fishing Mortality													
2018	0.002	0.029	0.074	0.100	0.078	0.066	0.034	0.017	0.002	0.012	-	-	-
2019	0.002	0.032	0.082	0.110	0.086	0.073	0.037	0.019	0.003	0.013	-	-	-
2020	0.002	0.032	0.082	0.110	0.086	0.073	0.037	0.019	0.003	0.013	-	-	-
Projected Population Numbers													
2018	**1719**	850	338	1064	1775	175	163	241	23	3	-	-	-
2019	**1719**	**1405**	676	257	788	1344	74	71	106	12	-	-	-
2020	**1719**	**1404**	**1114**	510	189	592	561	32	31	53	-	-	-
2021	**1719**	**1404**	**1114**	**840**	374	142	247	243	14	37	-	-	-
Projected Population Biomass													
2018	**236**	530	421	1864	4432	610	840	1172	162	33	-	9533	9112
2019	**193**	**974**	819	512	2319	5399	360	404	749	134	-	10697	9878
2020	**193**	**974**	**1350**	1016	555	2380	2742	182	221	612	-	9058	7707
2021	**193**	**974**	**1350**	**1675**	1100	569	1209	1386	99	434	-	7823	6473
Projected Catch Numbers													
2018	**3**	22	22	92	121	8	4	3	0	0	-	-	-
2019	**3**	**40**	48	24	59	65	2	1	0	0	-	-	-
2020	**3**	**40**	**79**	48	14	29	14	0	0	0	-	-	-
Projected Catch Biomass													
2018	**1**	22	41	261	533	41	25	26	0	0	951	-	-
2019	**1**	**40**	89	69	259	349	13	8	2	1	832	-	-
2020	**1**	**40**	**147**	137	62	154	96	4	1	5	647	-	-

Table 19. Projection and risk analysis result for eastern Georges Bank cod from the "M 0.8" model formulations: a) risk of fishery catch will exceed F reference point 0.11 in 2019 and 2020; and b) risk of ages 3+ biomass will not increase from 2019 to 2020 and from 2020 to 2021.

a)

Probability	0.25	0.5	0.75
2019	743 mt	860 mt	991 mt
2020(F_{2019}=0.11)	599 mt	668 mt	752 mt

b)

Probability	0.25	0.5	0.75
2019 to 2020	0 mt	0 mt	0 mt
2020 to 2021 (F_{2019}=0.11)	0 mt	0 mt	0 mt

Table 20. Deterministic projection results for eastern Georges Bank cod based on F reference point 0.11 and a flat top PR (avg 1994-2012). Shaded values are the 2010 year class (dark grey cells) and the 2013 year class (light grey cells). Bolded values show the year classes with assumed recruitments. A dash (-) indicates that this value was not calculated.

Parameter	Age												
	1	2	3	4	5	6	7	8	9	10+	1+	3+	4+
Fishing Mortality													
2018	0.001	0.007	0.045	0.075	0.075	0.060	0.067	0.075	0.060	0.015	-	-	-
2019	0.001	0.011	0.066	0.110	0.110	0.088	0.099	0.110	0.088	0.022	-	-	-
2020	0.001	0.011	0.066	0.110	0.110	0.088	0.099	0.110	0.088	0.022	-	-	-
Projected Population Numbers													
2018	**1719**	850	338	1064	1775	175	163	241	23	3	-	-	-
2019	**1719**	**1406**	690	265	809	1348	74	69	100	11	-	-	-
2020	**1719**	**1406**	**1139**	529	194	593	555	30	28	46	-	-	-
2021	**1719**	**1406**	**1138**	**873**	388	142	244	226	12	32	-	-	-
Projected Population Biomass													
2018	**241**	527	419	1862	4437	610	839	1174	162	33	-	9535	9116
2019	**189**	**970**	835	527	2377	5421	362	391	707	127	-	10747	9912
2020	**189**	**970**	**1378**	1053	571	2384	2708	172	195	535	-	8995	7617
2021	**189**	**970**	**1377**	**1737**	1141	573	1191	1287	86	367	-	7759	6381
Projected Catch Numbers													
2018	**1**	6	13	69	116	7	7	12	1	0	-	-	-
2019	**2**	**14**	40	25	76	79	5	5	6	0	-	-	-
2020	**2**	**14**	**66**	50	18	35	36	2	2	1	-	-	-
Projected Catch Biomass													
2018	**0**	6	25	197	512	37	50	112	11	0	951	-	-
2019	**0**	**14**	74	71	338	419	33	46	72	2	1070	-	-
2020	**0**	**14**	**123**	142	81	184	247	20	20	8	840	-	-

Table 21. Projection and risk analysis results for eastern Georges Bank cod from the "M 0.8" model a flat top PR (avg 1994-2012) with formulations: a) risk of fishery catch will exceed F reference point 0.11 in 2019 and 2020; and b) risk of ages 3+ will not increase from 2019 to 2020 and from 2020 to 2021.

a)

Probability	0.25	0.5	0.75
2019	936 mt	1,073 mt	1,224 mt
2020(F_{2019}=0.11)	754 mt	848 mt	957 mt

b)

Probability	0.25	0.5	0.75
2019 to 2020	0 mt	0 mt	0 mt
2020 to 2021 (F_{2019}=0.11)	0 mt	0 mt	0 mt

Table 22. Consequence analysis of different management actions taken for Atlantic cod from eastern Georges Bank. Projected catch and ages 3+ biomass are presented for each of two 'true state of nature' management models: VPA "M0.8" model with F=0.11 and rho adjusted ASAP M=0.2 model with Fref=0.18 during 2018-2020 on the main diagonal ("true state"). The risks of the alternative management actions "alternate state" are on the counter diagonal (see text). Fishing mortality (F), January 1 stock biomass, and percent change in biomass (% B) from the previous year are presented for each projection.

Consequence Analysis

Catch 2017	730 mt		
Quota 2018	951 mt		
		VPA 0.8	**ASAP**
2018 biomass (3+)		11,520	3,311
2019 biomass (3+)		9,502	3,478
Projected catch			
VPA F=0.11 at neutral risk		"true state"	"alternate state"
2019 catch = 860 mt	2019 F	0.11	0.31
	2020 Biomass (mt)	9,058	3,006
	% B from 2019	-15.3%	-14%
2020 catch = 668 mt	2020 F	0.11	0.24
	2021 Biomass (mt)	7,823	3,778
	% B from 2020	-13.6%	26%
ASAP F=0.18 median		"alternate state"	"true state"
2019 catch = 524 mt	2019 F	0.07	0.18
	2020 Biomass (mt)	9,290	3,339
	% B from 2019	-13.2%	-4%
2020 catch = 568 mt	2020 F	0.09	0.18
	2021 Biomass (mt)	8,060	4,189
	% B from 2020	-13.2%	25%

F ≤ Fref & biomass increase > 10%
F ≤ Fref & biomass increase < 10%
F > Fref & biomass increase < 10%
F > Fref & biomass increase > 10%

Table 23. Normalized ('Norm') swept area biomass indices and their associated coefficients of variation (CV), and the combined index and it's CV.

	NMFS Fall		NMFS Spring		DFO		Combined	
Year	Norm	CV	Norm	CV	Norm	CV	Norm	CV
1987	0.86	0.50	1.12	0.27	0.58	0.36	0.88	0.20
1988	1.04	0.50	1.37	0.35	1.29	0.32	1.26	0.21
1989	2.67	0.48	1.78	0.32	0.96	0.21	1.58	0.21
1990	2.03	0.45	1.60	0.31	3.75	0.28	2.57	0.20
1991	2.02	0.73	1.38	0.19	1.66	0.25	1.57	0.18
1992	0.17	0.56	0.90	0.22	0.97	0.25	0.80	0.16
1993	0.68	0.49	0.97	0.33	1.10	0.23	0.97	0.18
1994	0.24	0.61	0.19	0.33	0.87	0.51	0.40	0.35
1995	0.68	0.85	1.49	0.50	0.54	0.35	0.88	0.33
1996	0.48	0.64	0.98	0.43	2.13	0.31	1.39	0.24
1997	0.71	0.46	0.60	0.24	0.73	0.27	0.67	0.18
1998	0.74	0.99	1.81	0.48	0.33	0.23	0.81	0.33
1999	1.17	0.32	0.78	0.26	0.61	0.36	0.86	0.18
2000	0.41	0.68	1.09	0.28	2.14	0.46	1.27	0.27
2001	0.35	0.39	0.55	0.46	1.19	0.45	0.68	0.29
2002	0.46	0.61	0.65	0.28	1.35	0.43	0.83	0.25
2003	4.55	0.69	0.94	0.55	0.41	0.20	1.24	0.45
2004	0.24	0.48	3.11	0.63	0.37	0.30	0.95	0.47
2005	3.30	0.80	0.65	0.25	1.73	0.60	1.40	0.39
2006	0.57	0.47	1.08	0.28	0.83	0.30	0.87	0.19
2007	0.85	0.81	0.89	0.30	0.74	0.28	0.82	0.21
2008	0.17	0.41	0.79	0.28	0.90	0.29	0.67	0.19
2009	0.31	0.34	0.64	0.33	1.53	0.68	0.69	0.33
2010	0.47	0.42	0.53	0.24	1.74	0.66	0.74	0.32
2011	0.29	0.44	0.25	0.36	0.56	0.27	0.39	0.20
2012	0.91	0.73	0.72	0.28	0.16	0.22	0.48	0.26
2013	0.24	0.42	1.42	0.63	0.74	0.50	0.72	0.38
2014	1.01	0.67	0.48	0.33	0.16	0.29	0.44	0.32
2015	0.54	0.54	0.26	0.24	0.24	0.39	0.31	0.24
2016	1.41	0.43	0.53	0.58	0.24	0.25	0.64	0.30
2017	2.15	0.37	1.99	0.50	0.96	0.61	1.79	0.27
2018	0.26	0.71	0.46	0.67	0.48	0.38	0.42	0.31

Table 24. Estimated slope from the robust least squares fit (bc=bias corrected; bs=bootstrap) for 5-25-50-75-95 percentiles, for the robust least square loess fit.

Year	Slope	Mean_bs	Bias_adj	bc_0.5	bc_0.05	bc_0.95	bc_0.25	bc_0.75
1993	0.72	0.81	0.09	0.63	0.66	0.50	0.85	0.62
1994	0.84	0.91	0.07	0.77	0.76	0.64	0.92	0.69
1995	1.15	1.06	-0.09	1.24	1.38	0.98	1.64	1.15
1996	1.16	1.10	-0.06	1.22	1.24	0.93	1.48	1.10
1997	1.02	1.04	0.02	1.00	1.01	0.89	1.17	0.93
1998	0.94	1.01	0.08	0.86	0.91	0.88	1.04	0.90
1999	1.00	1.02	0.01	0.99	1.02	0.83	1.24	0.93
2000	1.06	1.01	-0.05	1.11	1.08	0.93	1.20	1.04
2001	1.00	1.01	0.00	1.00	0.99	0.93	1.08	0.95
2002	0.98	1.03	0.05	0.93	0.93	0.89	1.06	0.91
2003	1.06	1.08	0.02	1.04	1.05	0.89	1.24	0.97
2004	1.14	1.09	-0.05	1.20	1.20	1.05	1.28	1.14
2005	1.05	1.03	-0.02	1.07	1.07	0.97	1.16	1.03
2006	0.91	0.94	0.03	0.89	0.90	0.85	0.99	0.87
2007	0.85	0.87	0.03	0.82	0.80	0.78	0.90	0.79
2008	0.85	0.86	0.02	0.83	0.82	0.79	0.93	0.80
2009	0.92	0.89	-0.04	0.96	0.95	0.88	0.97	0.93
2010	0.92	0.91	-0.01	0.93	0.93	0.83	1.01	0.90
2011	0.89	0.92	0.03	0.85	0.87	0.82	0.97	0.84
2012	0.95	0.94	-0.01	0.95	0.96	0.83	1.07	0.91
2013	0.98	0.97	-0.01	0.99	0.99	0.81	1.14	0.91
2014	0.97	0.98	0.02	0.95	0.95	0.82	1.11	0.89
2015	0.98	0.98	0.01	0.97	0.97	0.81	1.16	0.91
2016	0.98	0.98	0.00	0.98	0.98	0.84	1.14	0.94
2017	0.96	0.98	0.01	0.95	0.96	0.90	1.05	0.93
2018	0.97	0.98	0.01	0.96	0.96	0.85	1.14	0.90

Table 25. Quota advice (mt) resulting from application of the empirical method.

Year	5%	25%	50%	75%	95%
2018	566	600	644	697	763

Table 26. Comparison of TRAC catch advice, TMGC quota decision, actual catch, and resulting fishing mortality and biomass changes for eastern Georges Bank cod.

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch[(1)] /Compared to Risk Analysis	Actual F Result[(2)]
		Amount	**Rationale**	**Amount**	**Rationale**		
1999[(3)]	1999	3,100 mt		NA	NA	3,000 mt	*Near* $F_{0.1}$
2000	2000	3,750 mt	$F_{0.1}$	NA	NA	2,250 mt	*Less than* $F_{0.1}$
2001	2001	3,500 mt	$F_{0.1}$	NA	NA	3,500 mt	*Above* $F_{0.1}$
2002	2002	1,900 mt	$F_{0.1}$	NA	NA	2,800 mt	*F = 0.23*
Transition to TMGC process in following year; note catch year differs from TRAC year in following lines							
2003	2004	1,300 mt	Neutral risk of exceeding Fref. 20% chance of decrease in biomass from 2004-2005.	1,300 mt	Neutral risk of exceeding Fref. 20% chance of decrease in biomass from 2004-2005.	2,332 mt Exceed Fref and biomass to decline	*F=0.16* *Biomass decreased 23%* Now F = 0.38 Biomass decreased 74% 04 - 05
2004	2005	1,100 mt	Neutral risk of exceeding Fref. Greater than 50% risk of decline in biomass from 2005 - 2006.	1,000 mt	Low risk of exceeding Fref, neutral risk of stock decline	1,287 mt Greater than neutral risk of exceeding $F_{0.1}$; biomass expected to decline 10%	*F=0.10* *Biomass stabled* Now F = 0.23 Biomass increased 18% 05 - 06
2005	2006	2,200 mt	Neutral risk of exceeding Fref. Low risk of less than 10% biomass increase from 2006 - 2007.	1,700 mt	Low risk of exceeding Fref, 75% probability of stock increase of 10%	1,705 mt Approx 25% risk of exceeding Fref; biomass increase not likely to be 20%	*F=0.15* *Biomass stabled* Now F = 0.38 Biomass decreased 4% 06 - 07
2006[(4)]	2007	(1) 2,900 mt (2) 1,500 mt	(1) Neutral risk of exceeding Fref. (2) Neutral risk of biomass decline from 2007 – 2008.	1,900 mt	Low risk of exceeding Fref, nominal decline in stock size	1,811mt No risk of exceeding Fref; neutral risk of biomass decline	*F=0.13* *Biomass stabled* Now F = 0.30 Biomass increased 7% 07-08
2007[(4)]	2008	2,700 mt	Neutral risk of exceeding Fref and a neutral risk of stock decline from 2008 - 2009	2,300 mt	Low risk of exceeding Fref, nominal stock size increase	1,780 mt No risk of exceeding Fref; biomass not expected to increase 10%	*F = 0.25 or 0.17* *Biomass increased 16%/19%* Now 0.30; Biomass increased 8% 08-09;

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch[(1)] /Compared to Risk Analysis	Actual F Result[(2)]
2008[(4)]	2009	(1) 2,100 mt (2) 1,300 mt	(1) Neutral risk of exceeding Fref (2) neutral risk of stock decline from 2009 - 2010	1,700 mt	Low risk of exceeding Fref, high risk biomass will not increase	1,837 mt Slightly less than neutral risk of exceeding Fref; biomass almost certain not to increase	*F = 0.33 or 0.20* *Biomass stable or declined 7%* Now F=0.17; Biomass decreased 33% 09-10;
2009[(4)]	2010	(1) 1,300 – 1,700 mt (2) 1,800 – 900 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2010 - 2011	1,350 mt	Neutral risk of biomass decline	1,326 mt	*F = 0.41 or 0.25* *Biomass decreased 15%/ 17%* Now F=0.29; Biomass decreased 43% 10-11;
2010[(4)]	2011	(1) 1,000 – 1,400 mt (2) 1,850 – 1,350 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2011 - 2012	1,050 mt	Low risk of exceeding Fref, and biomass growth of up to 10%.	1,037 mt	*F = 0.49 or 0.28* *Biomass increased 6%/stable* Now F= 0.41; Biomass decreased 31% 11-12
2011	2012	(1) 600 – 925 mt (2) 1,350 – 900 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock decline from 2012 – 2013	675 mt	Low risk of exceeding Fref, and low to neutral risk of biomass decline	614 mt	*F=0.07;* *Biomass increased 16%* Now F= 0.43; Biomass increased 41% 12-13
2012	2013	(1) 400 – 775 mt (2) 400 – 575 mt	(1) Neutral risk of exceeding Fref (2) Neutral risk of stock not increase by 20% from 2013 – 2014	600 mt	Neutral risk of exceeding Fref, and stock biomass increase more than 10%	463 mt	*F=0.04;* *Biomass increased 9%* F=0.14; Biomass increased 21% 13-14
2013	2014	600 mt	(1) low risk of exceeding Fref (2) Neutral risk of stock not increase by10% from 2014 – 2015	700 mt	Low risk of exceeding Fref, and stock biomass increase close to 10%	574 mt	*F=0.04;* *Biomass increased 10%* F=0.06; Biomass increased by 17% 14-15

TRAC	Catch Year	TRAC Analysis/Recommendation		TMGC Decision		Actual Catch[(1)] /Compared to Risk Analysis	Actual F Result[(2)]
2014	2015	<675 mt	(1) low risk of exceeding Fref (2) even with no fishing in 2016 there is a greater than 50% risk of a decrease in adult biomass from 2016 to 2017	650 mt	Low risk of exceeding Fref, but high risk of decrease in adult biomass	608 mt	*F=0.05* *Biomass increased 29%* F=0.05; Biomass increased by 33% 15-16
2015	2016	<650 mt	(1) Neutral risk of exceeding Fref (2) even with no fishing in 2016 there is a greater than 50% risk of a decrease in adult biomass from 2016 to 2017	625 mt	Neutral risk of exceeding Fref, but high risk of decrease in adult biomass	537 mt	*F=0.05* *Biomass increased by 11%* F=0.05 Biomass decreased by 2% 16-17
2016	2017	700 mt	(1) low risk of exceeding Fref	730 mt	Fishing mortality rate (F) similar to 2016	526 mt	*F=0.04* *Biomass decreased by 21%*
2017	2018	730-900 mt	Lower bound: no reason to recommend reducing catch advice below the 2017 quota. Upper bound: reflects a reduction from the VPA Fref and recognizes the potential that 2018 VPA projected catches are likely to be optimistically high.	951	Fishing mortality rate (F) below the fishing mortality reference point (0.11) based on the benchmark model, and is lower than the results of the empirical approach.		

(1) All catches are calendar year catches
(2) Values in italics are assessment results in year immediately following the catch year; values in normal font are results from this assessment
(3) Prior to implementation of US/CA Understanding
(4) Advice and results reported for two assessment models

FIGURES

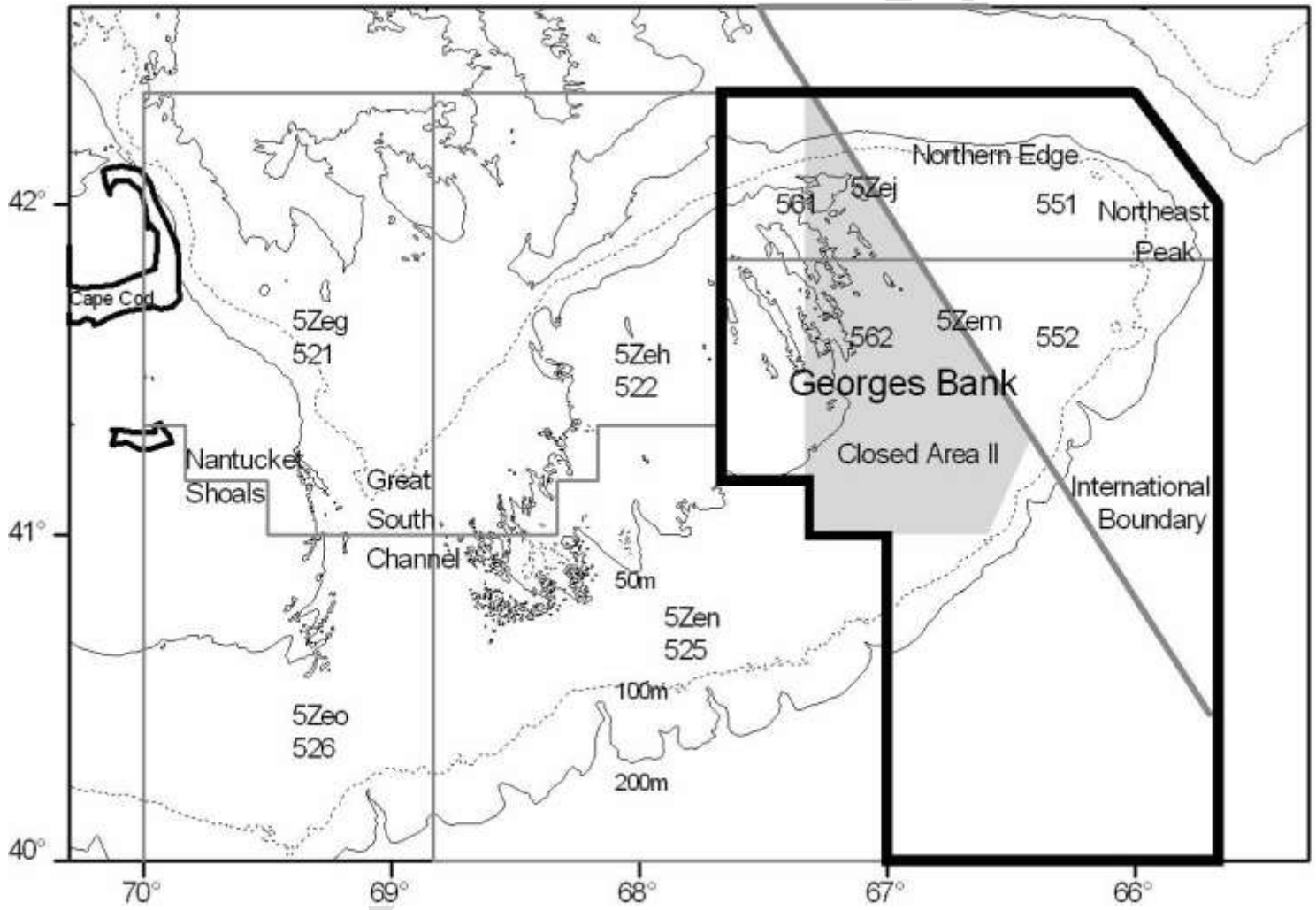

Figure 1. Fisheries statistical areas (Canada and USA) in NAFO Subdivision 5Ze. The eastern Georges Bank Atlantic Cod management unit is outlined by a heavy black line.

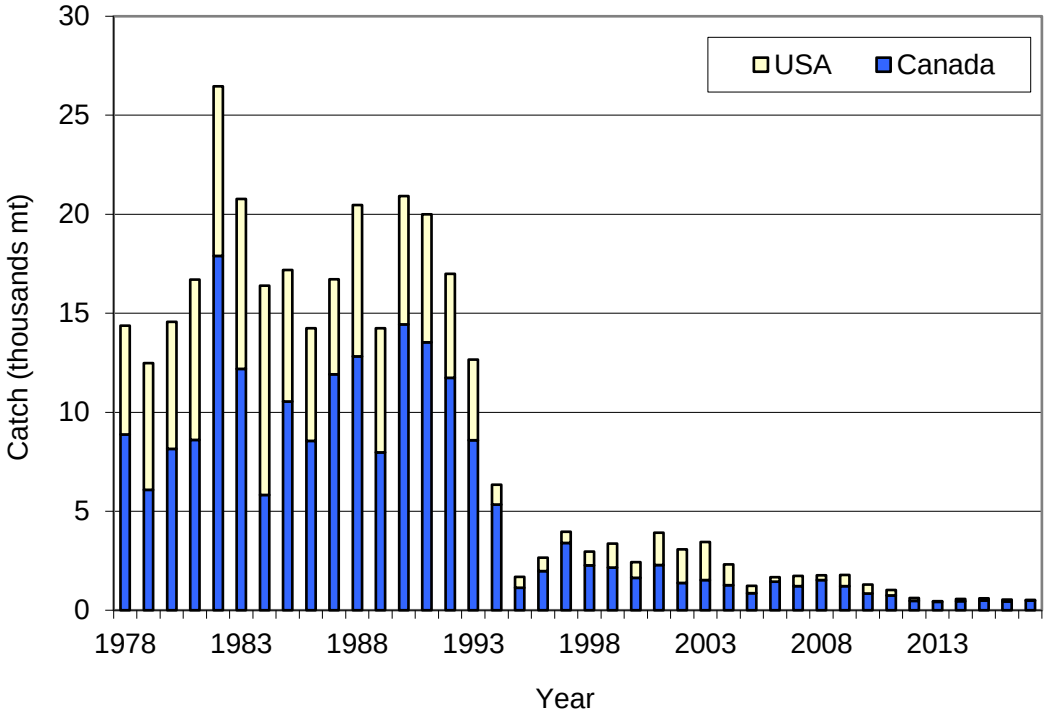

Figure 2. Catches eastern Georges Bank cod, 1978 to 2017.

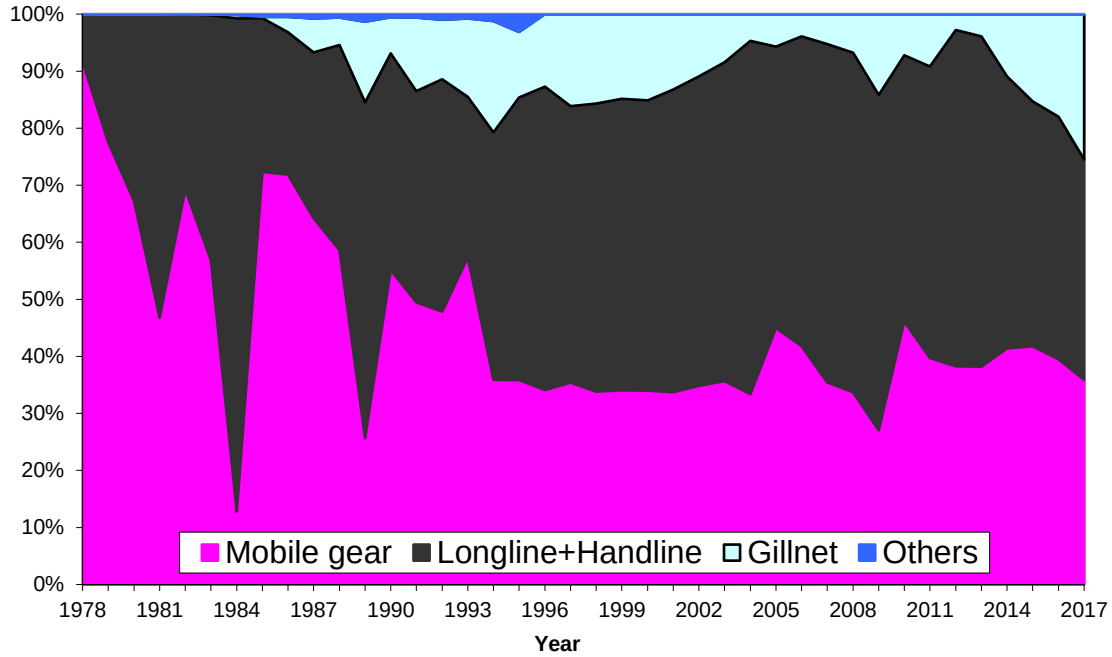

Figure 3. Proportion of Canadian (upper) and US (lower) gear specific landings of cod from eastern Georges Bank for 1978 to 2017.

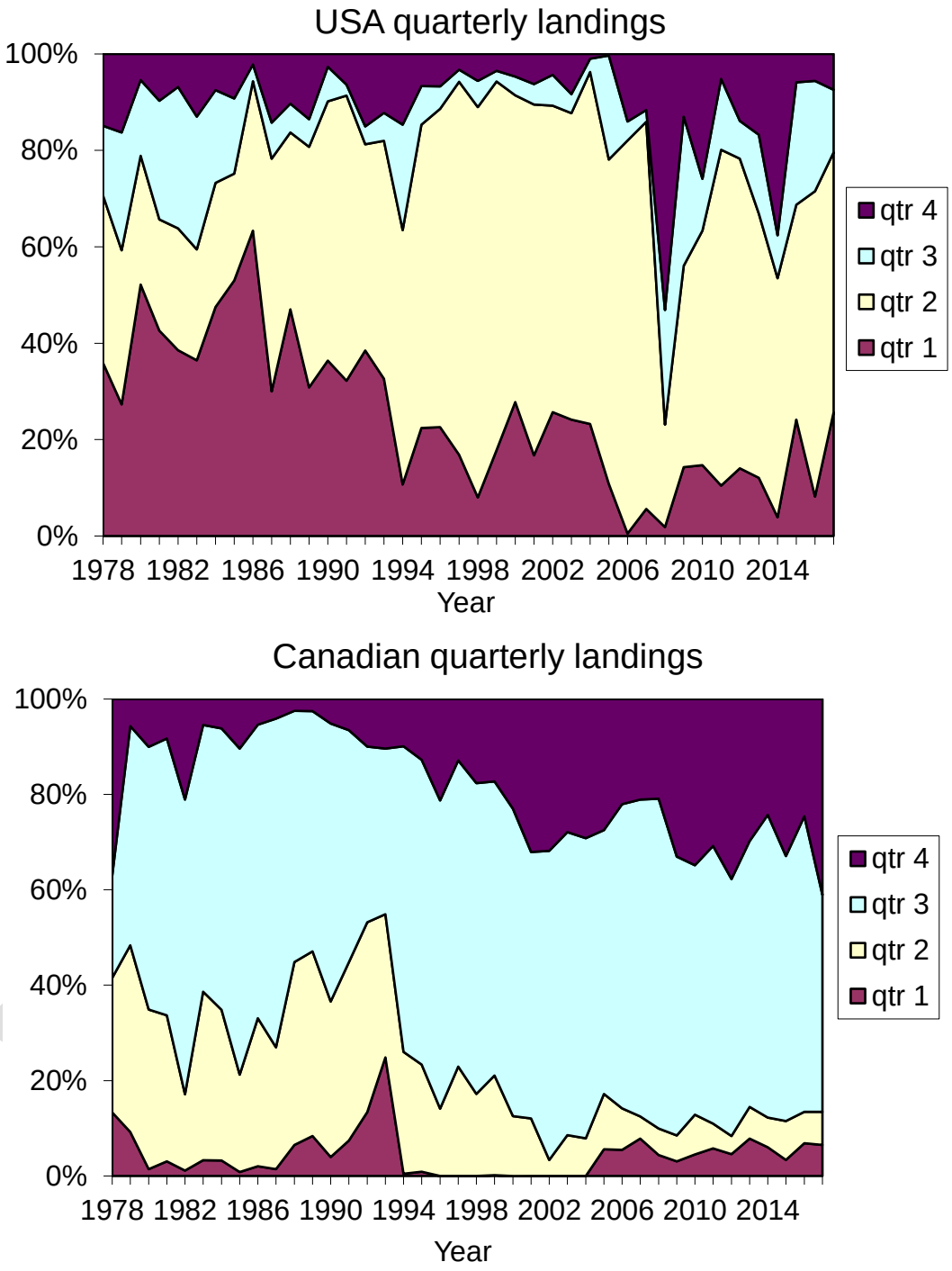

Figure 4. Proportion of Canadian (upper) and USA (lower) quarterly landings of cod from eastern Georges Bank, 1978 to 2017.

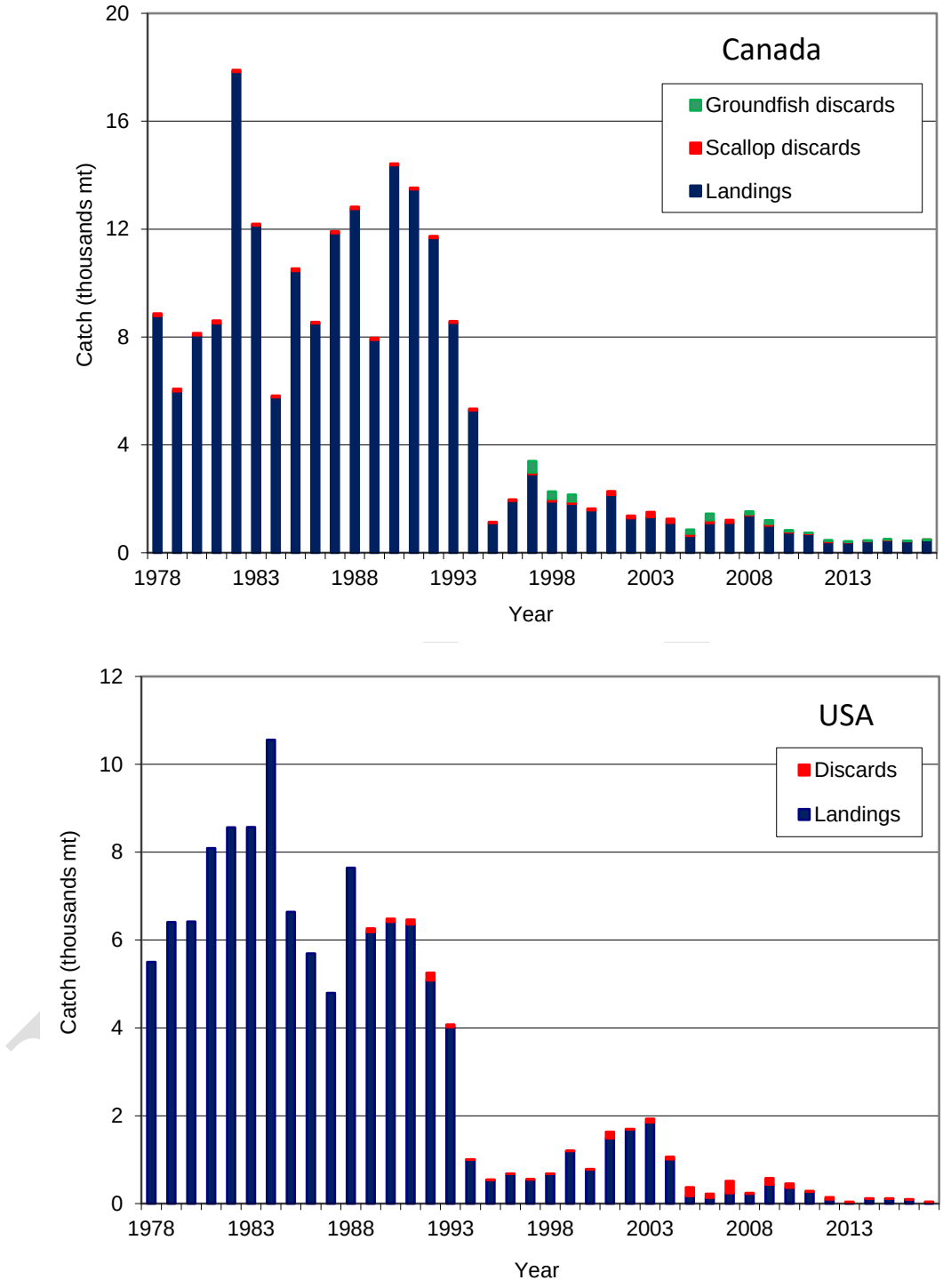

Figure 5. Canadian (upper) and and USA (lower) landings and discards of eastern Georges Bank cod, 1978 to 2017.

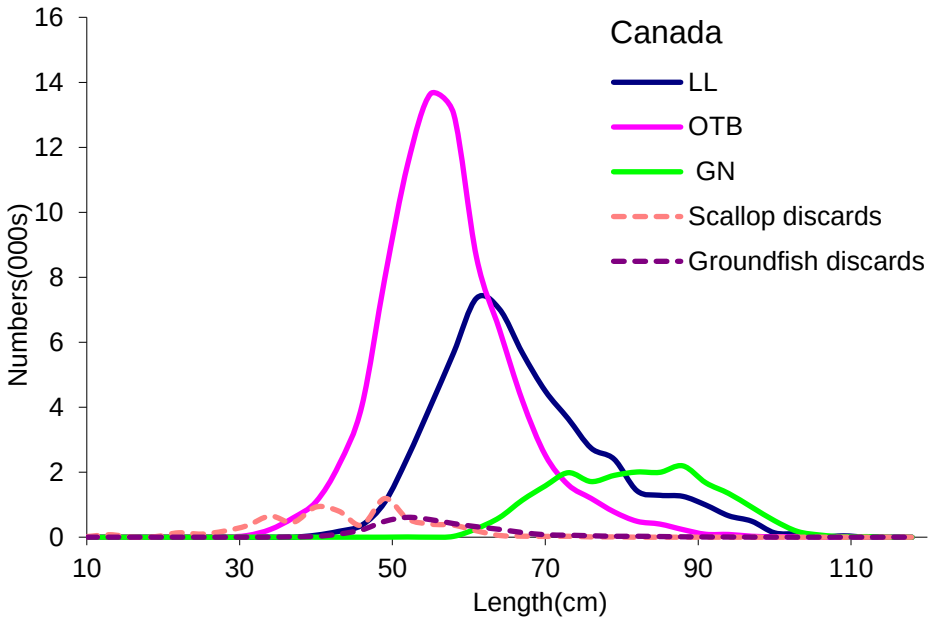

Figure 6. Cod catches at length by gear from the 2017 Canadian fisheries bottom trawl (OTB), longline (LL) and gillnet (GN) fisheries on eastern Georges Bank.

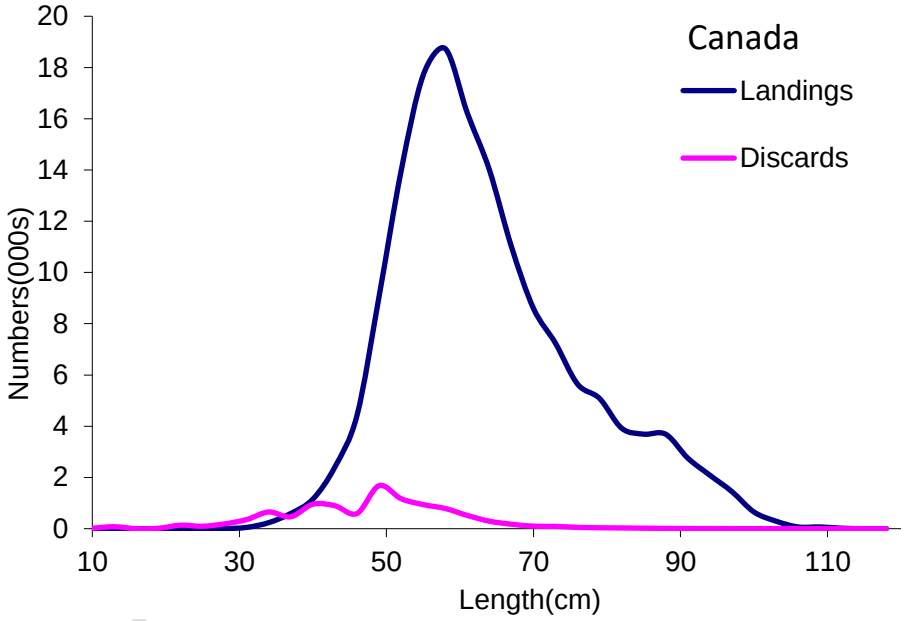

Figure 7. Cod landings and discards at length from the 2017 Canadian fisheries on eastern Georges Bank.

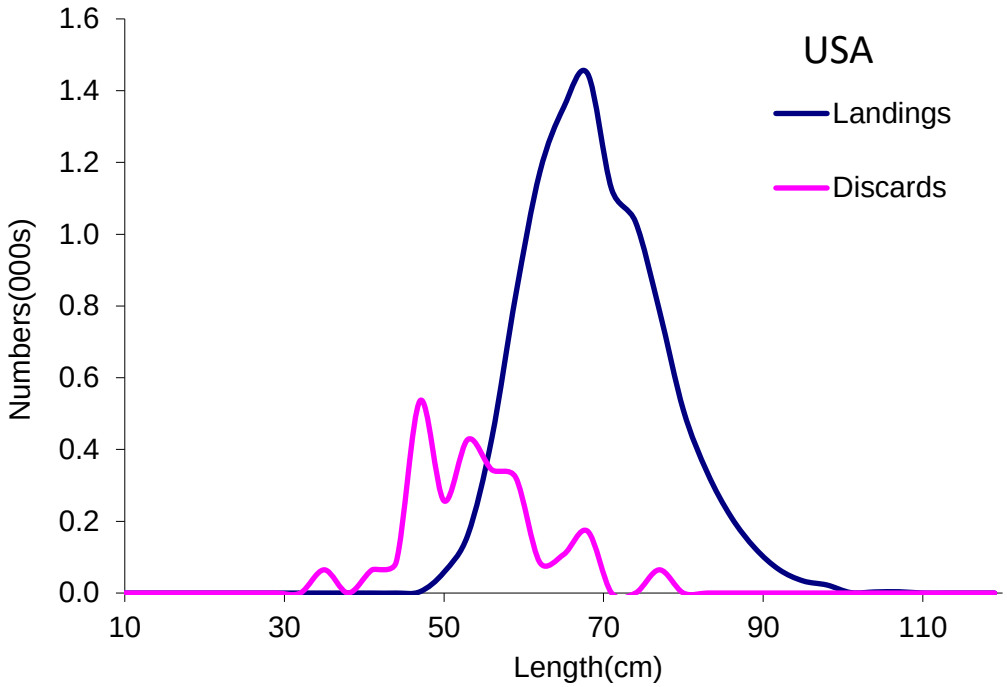

Figure 8. Cod landings and discards at length from the 2017 USA fisheries on eastern Georges Bank.

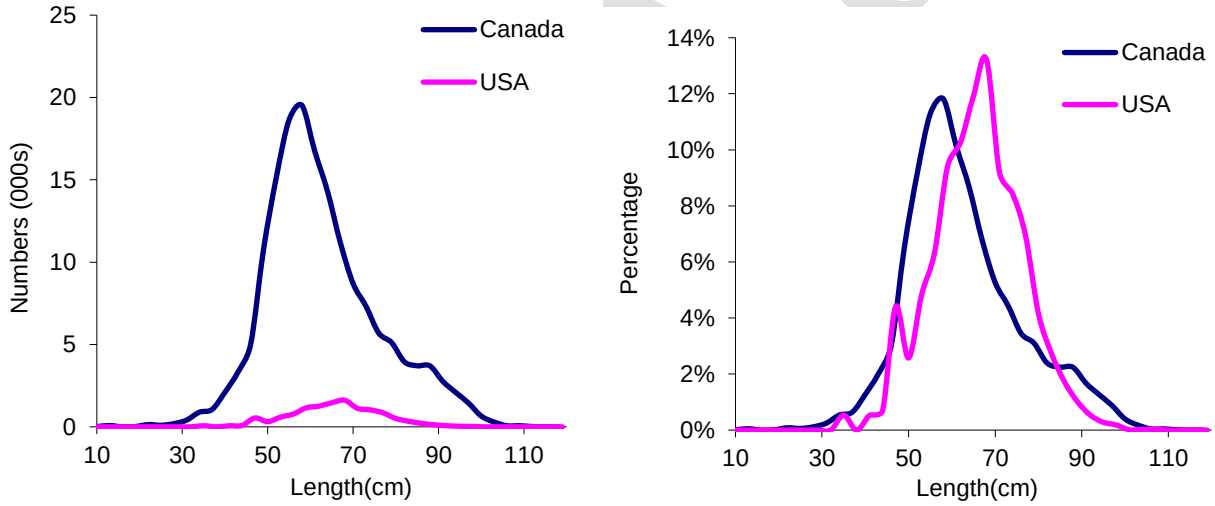

Figure 9. Cod length frequency from the 2017 Canadian and USA fisheries on eastern Georges Bank in numbers (left) and percent (right).

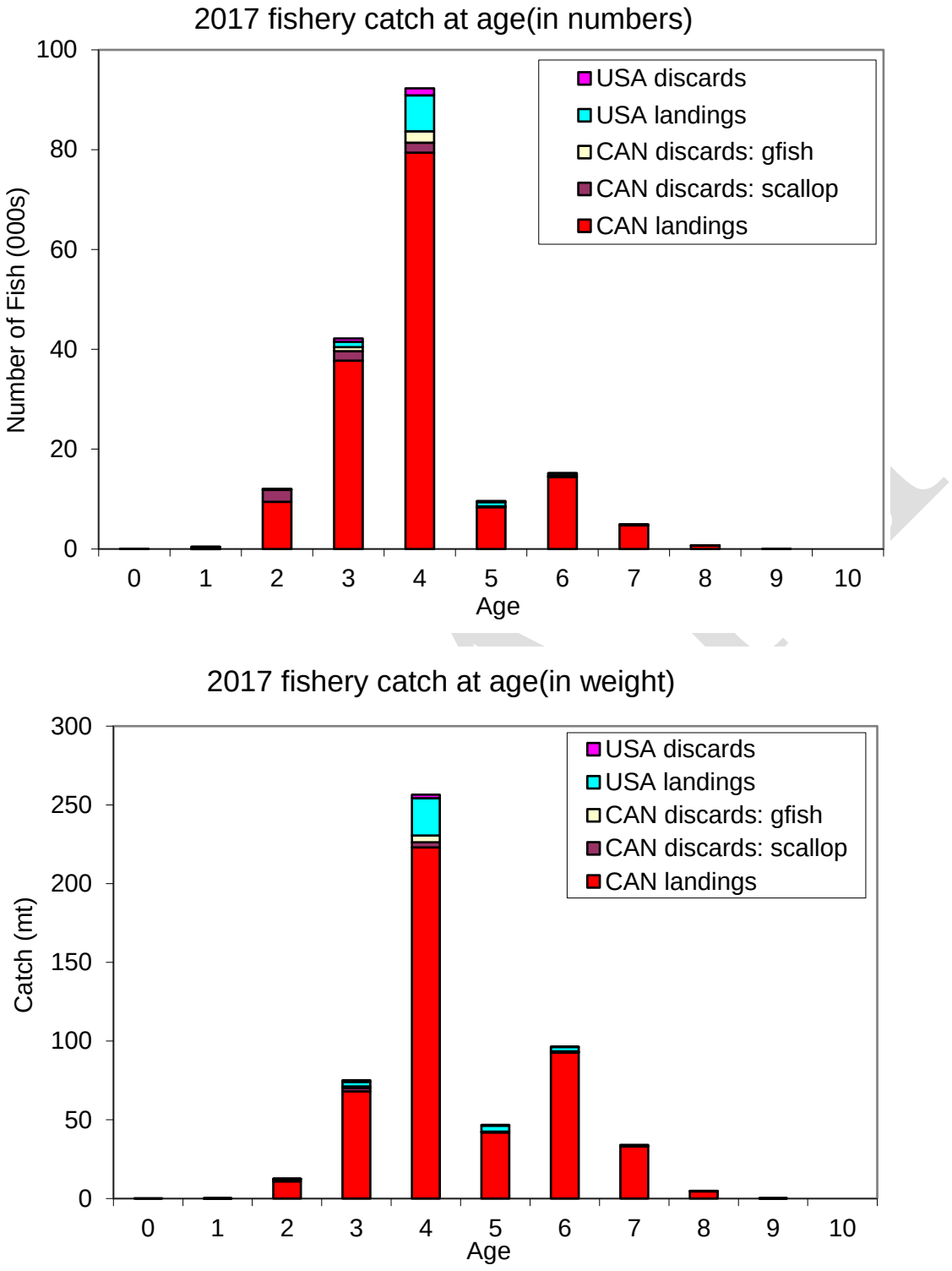

Figure 10. Catch at age in numbers (left) and weight (right) for landings and discards of cod from the 2017 eastern Georges Bank fisheries.

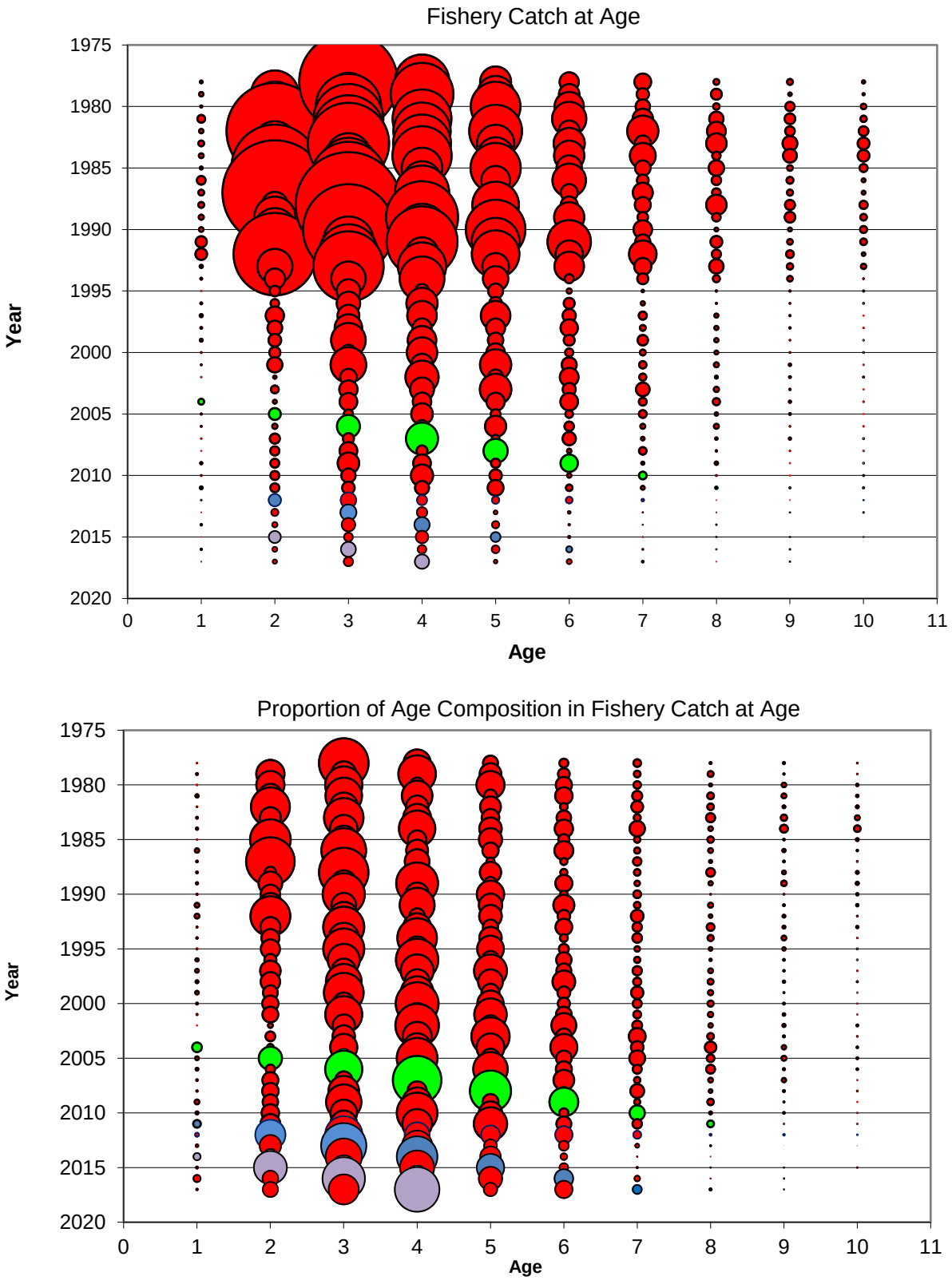

Figure 11. Total catch at age (numbers) of cod (left) and proportion of catch at age from eastern Georges Bank for 1978 to 2017. The bubble area is proportional to the magnitude. The green denotes the 2003 year class, the blue denotes the 2010 year class and the purple denotes the 2013 year class.

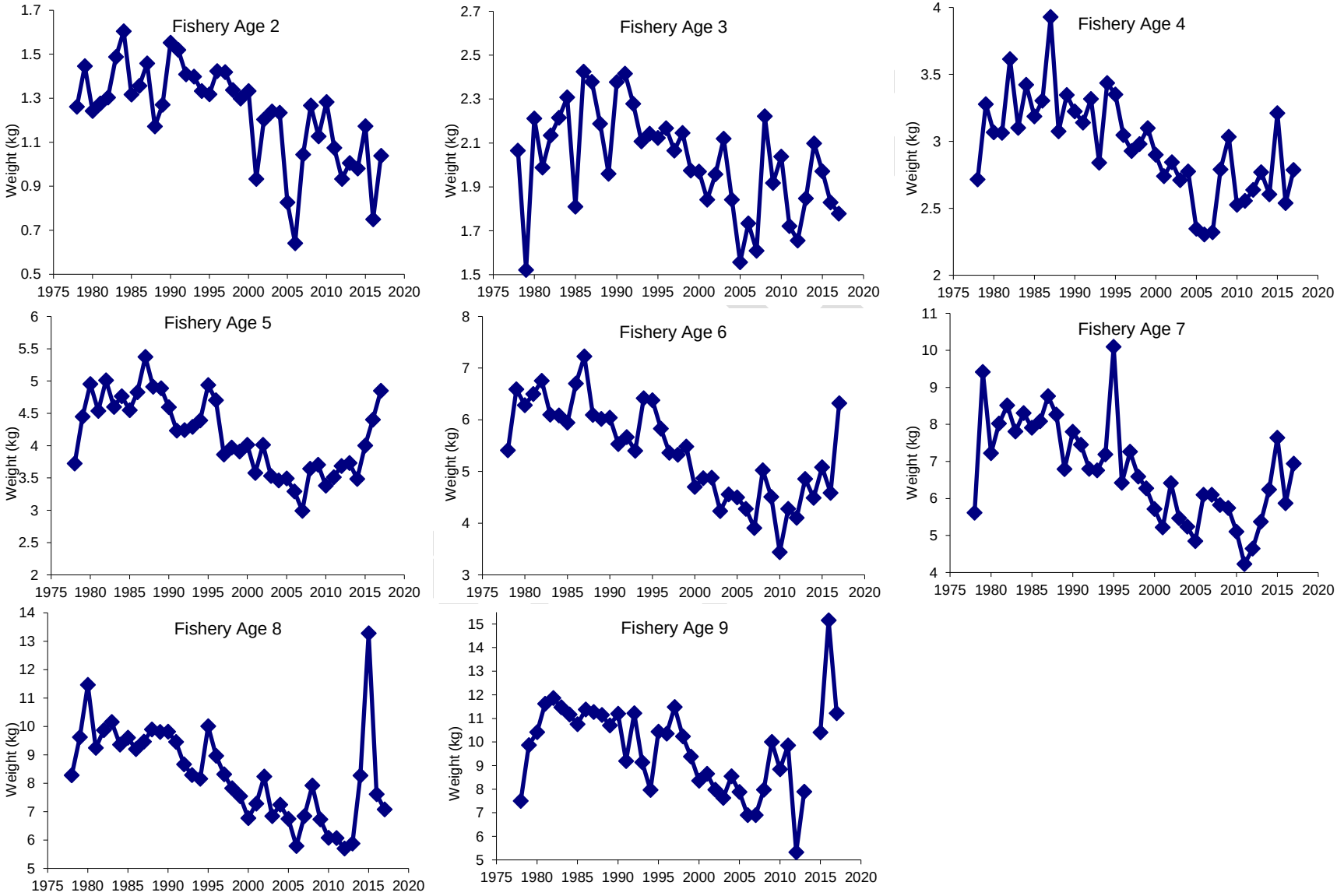

Figure 12. Average weight at age for ages 2 to 9 of cod from the eastern Georges Bank fishery, 1978-2017.

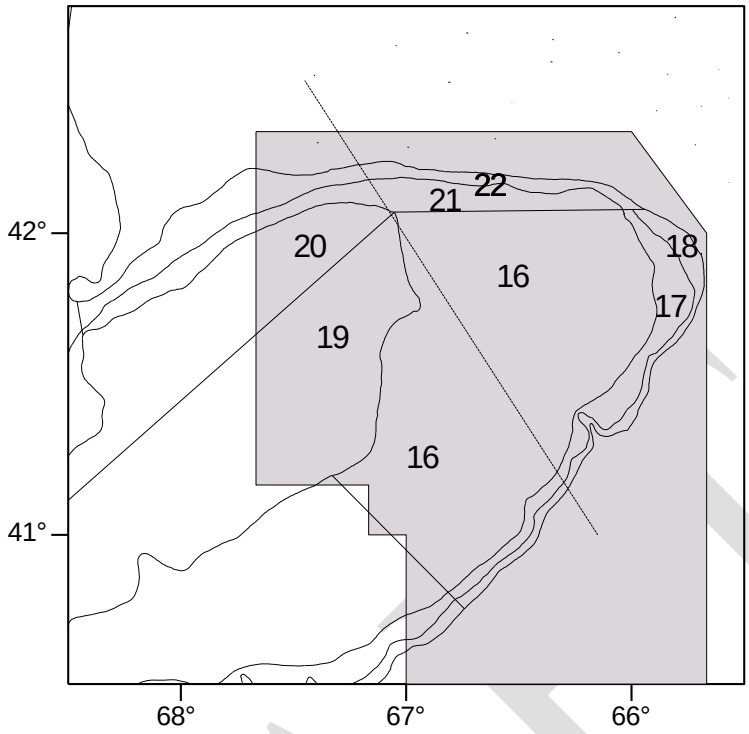

Figure 13. Stratification used for the NMFS surveys. The eastern Georges Bank management unit is indicated by shading.

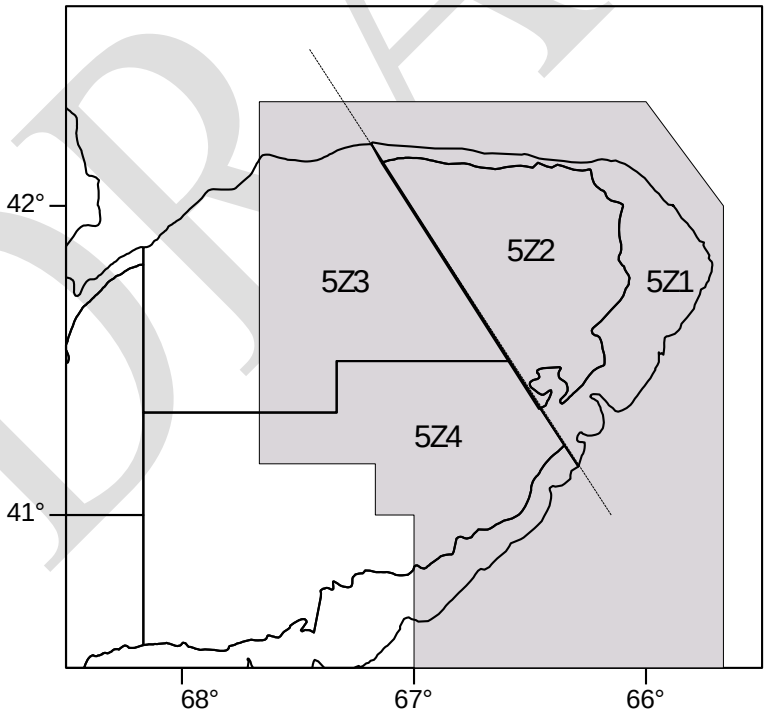

Figure 14. Stratification used for the DFO survey. The eastern Georges Bank management unit is indicated by shading.

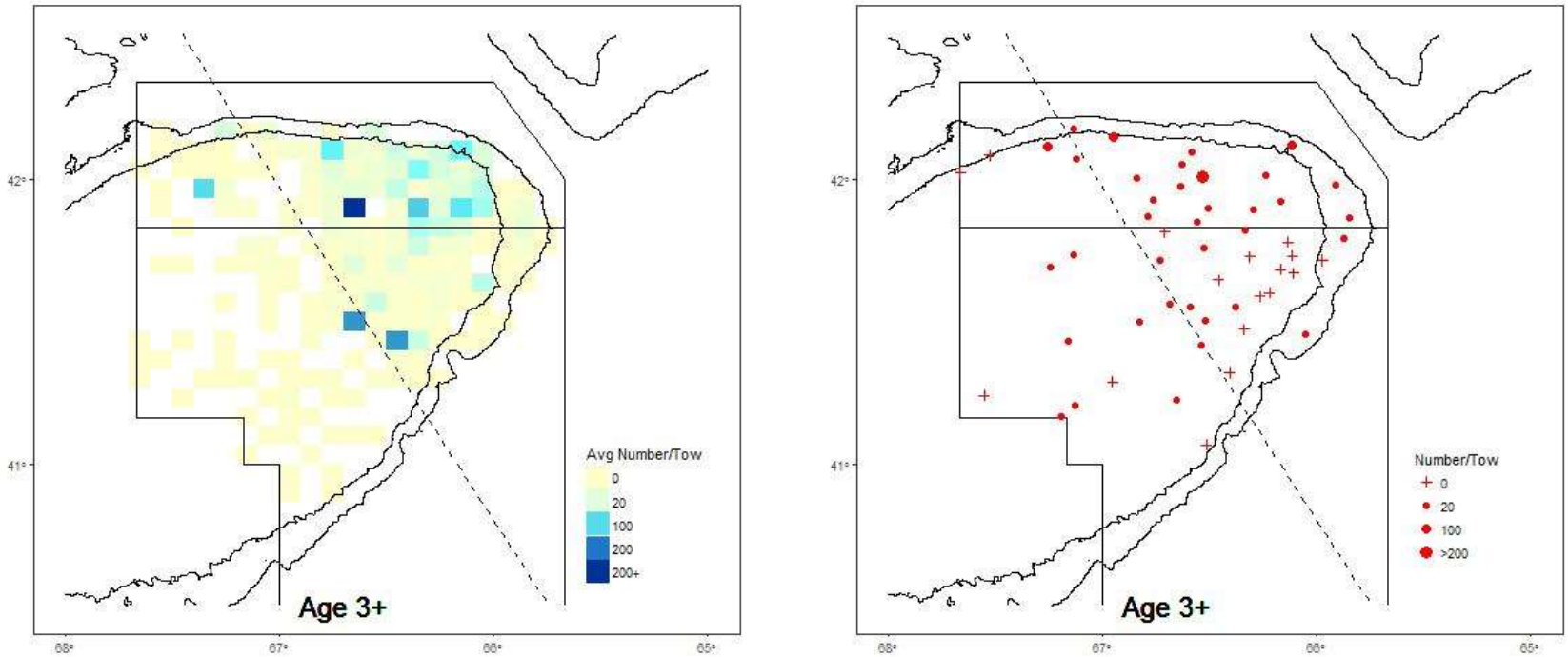

Figure 15. Spatial distribution of age 3+ cod on eastern Georges Bank from the DFO survey for 2018 (right) compared to the average for 2008-2017 (left).

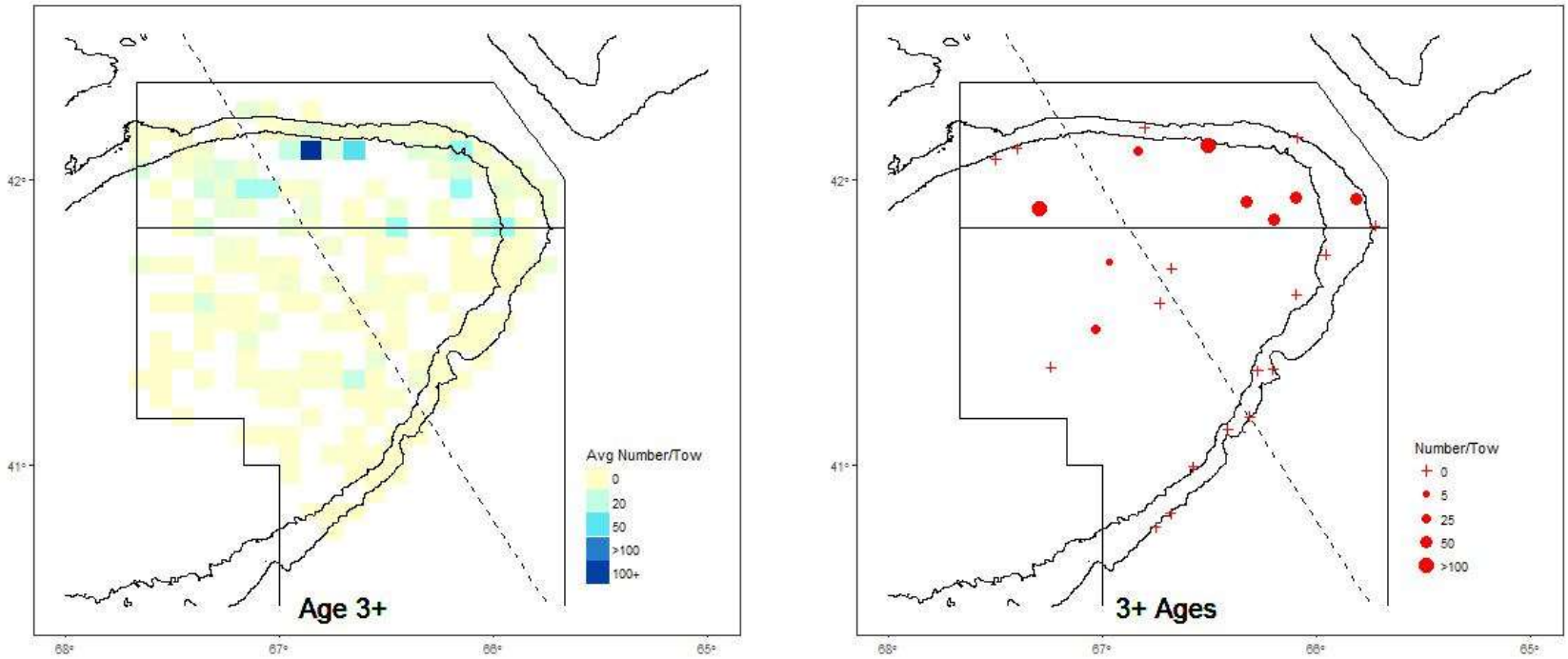

Figure 16. Spatial distribution of cod (all ages) on eastern Georges Bank from the NMFS spring survey for 2018 (right panel) compared to the average age 3+ cod for 2008-2017 (left panel).

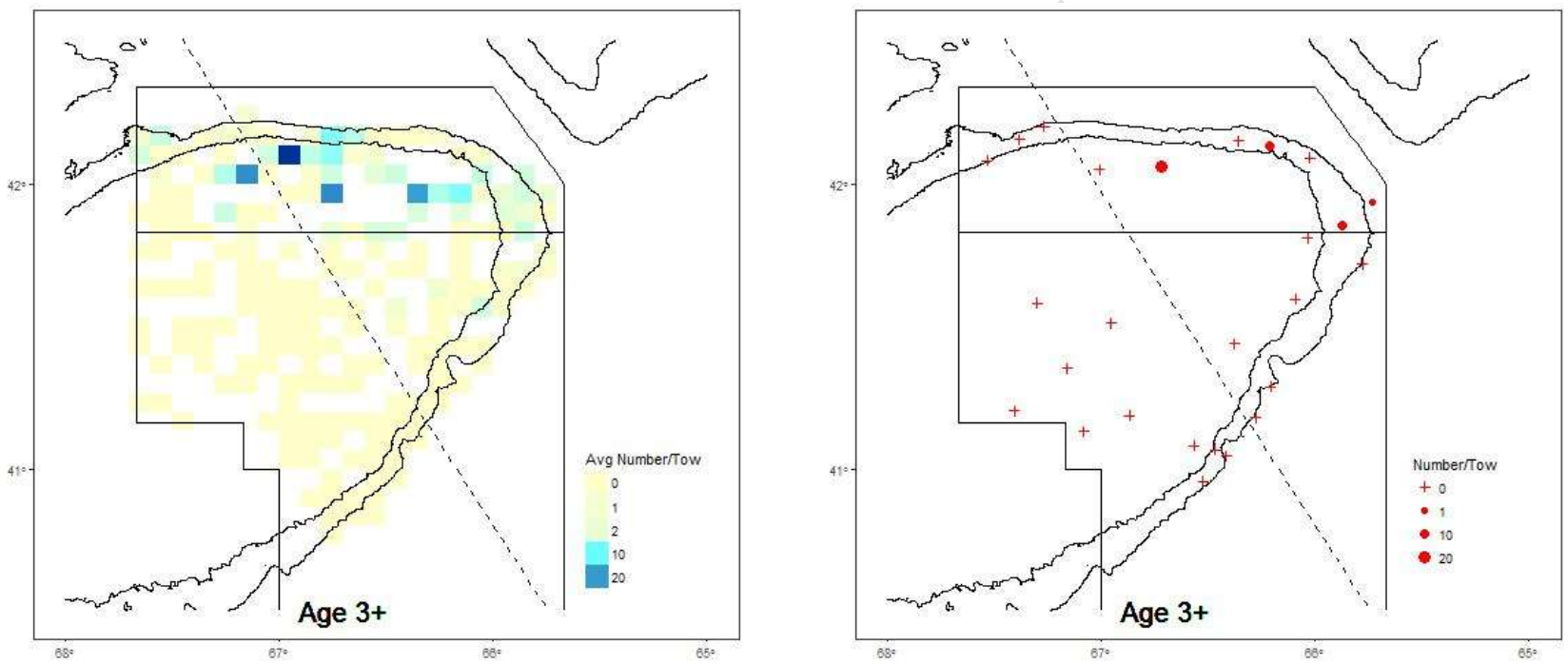

Figure 17. Spatial distribution of age 3+ cod on eastern Georges Bank from the NMFS fall survey for 2017 (right) compared to the average for 2007-2016 (left).

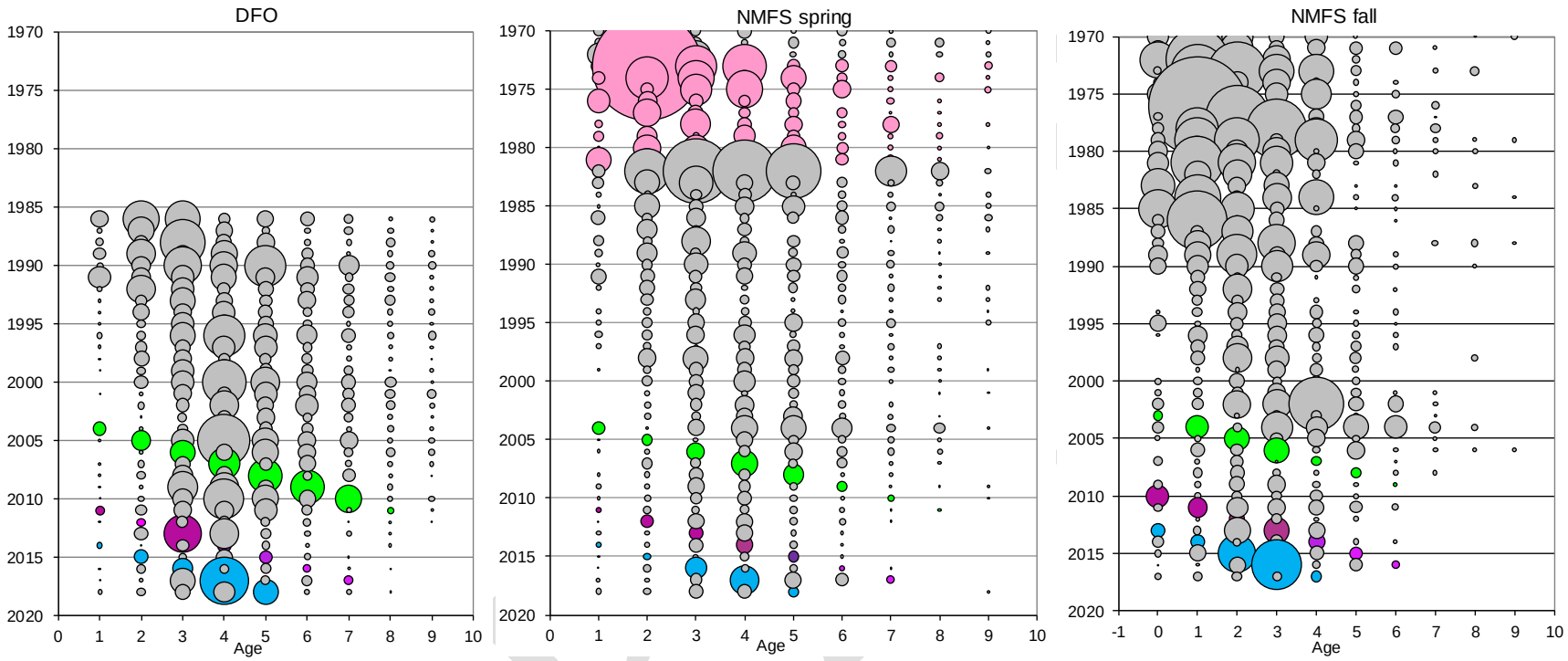

Figure 18. Survey abundance at age (numbers) of eastern Georges Bank cod. The bubble area is proportional to magnitude within each survey. Conversion factors to account for changes in door type, net and survey vessel were applied to the NMFS surveys. The NMFS spring survey was conducted using a modified Yankee 41 during 1978 to 1981 (lighter bubbles). The 2003 year class is identified with green bubbles, the purple bubbles show the 2010 year class and the blue show the 2013 year class.

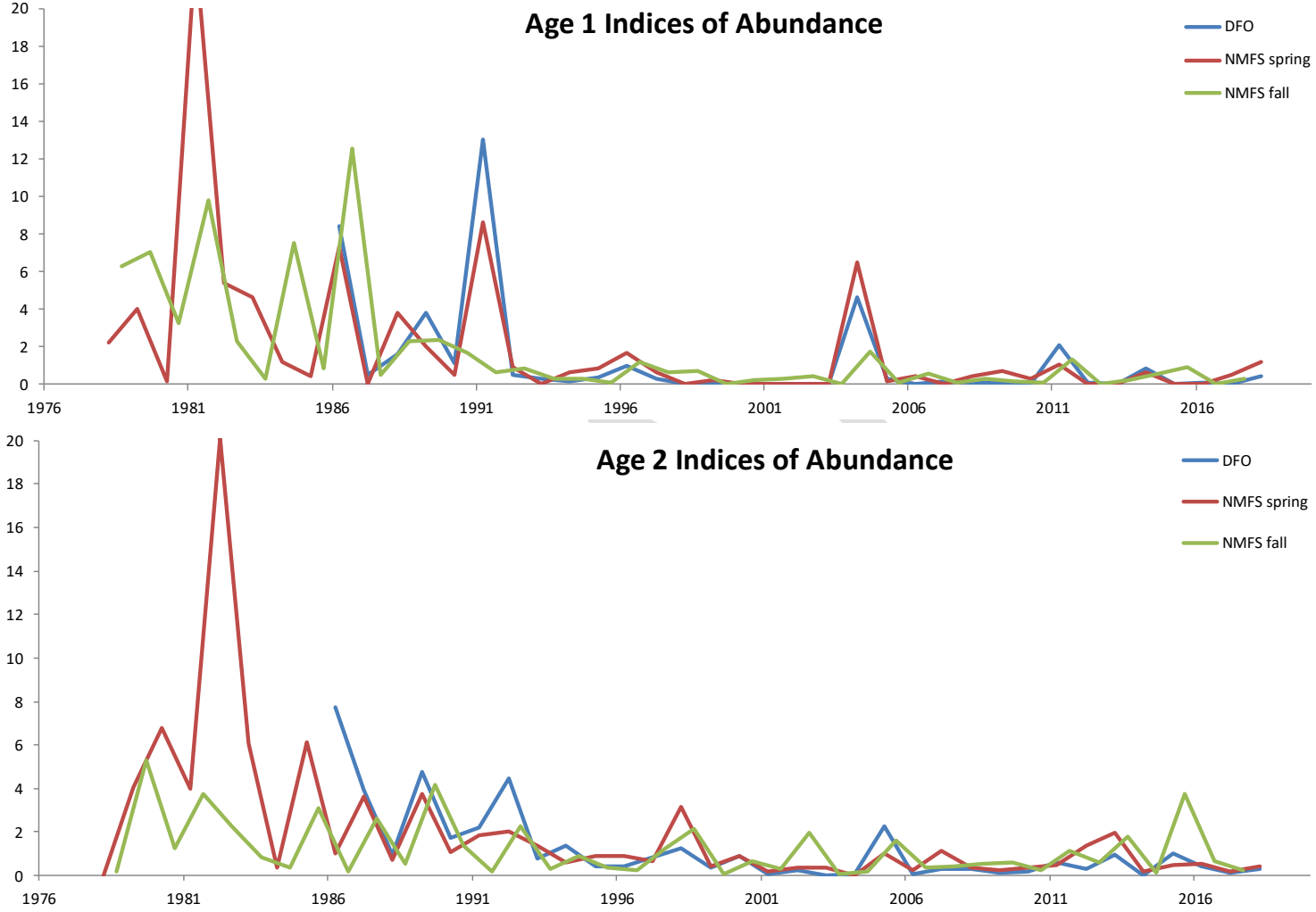

Figure 19. Numbers of age 1 (top) and age 2 (bottom) cod from the NMFS fall, spring, and DFO surveys scaled to the mean (1987-2018).

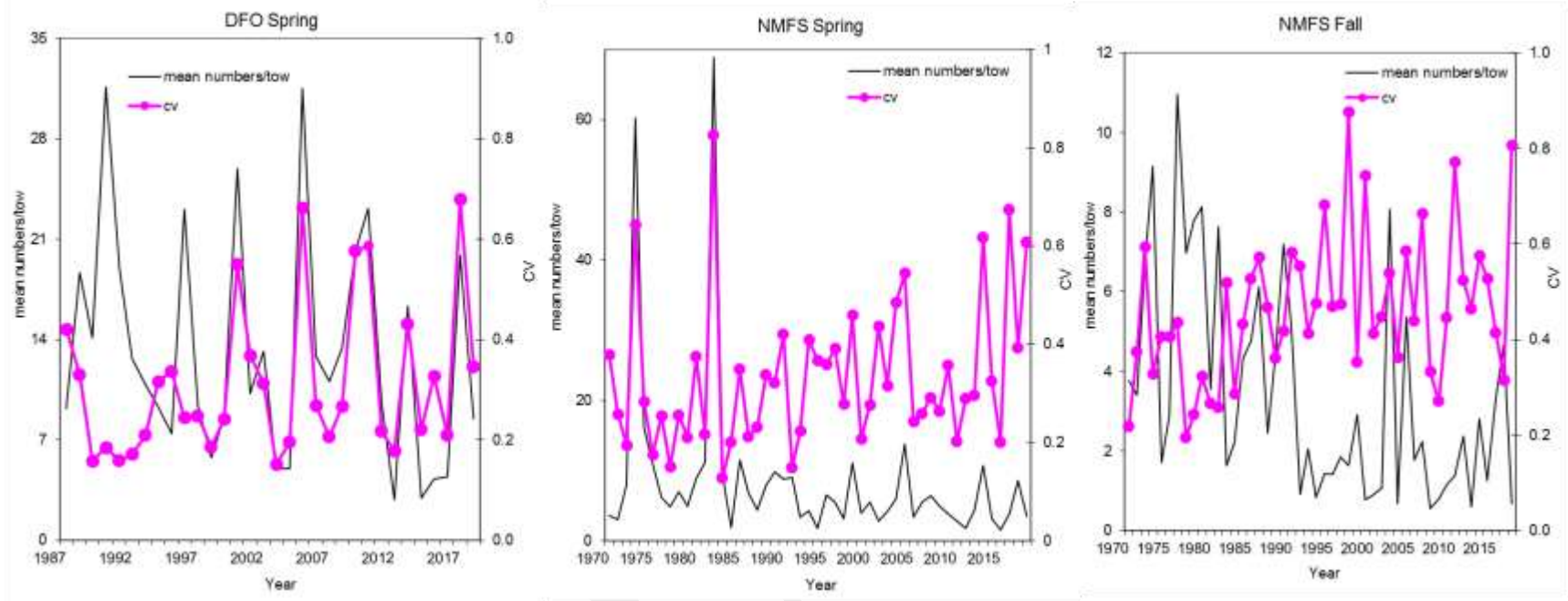

Figure 20. Stratified mean number per tow and coefficient of variation (CV) for DFO (left), NMFS spring (middle) and NMFS fall (right) survey catch of eastern Georges Bank cod.

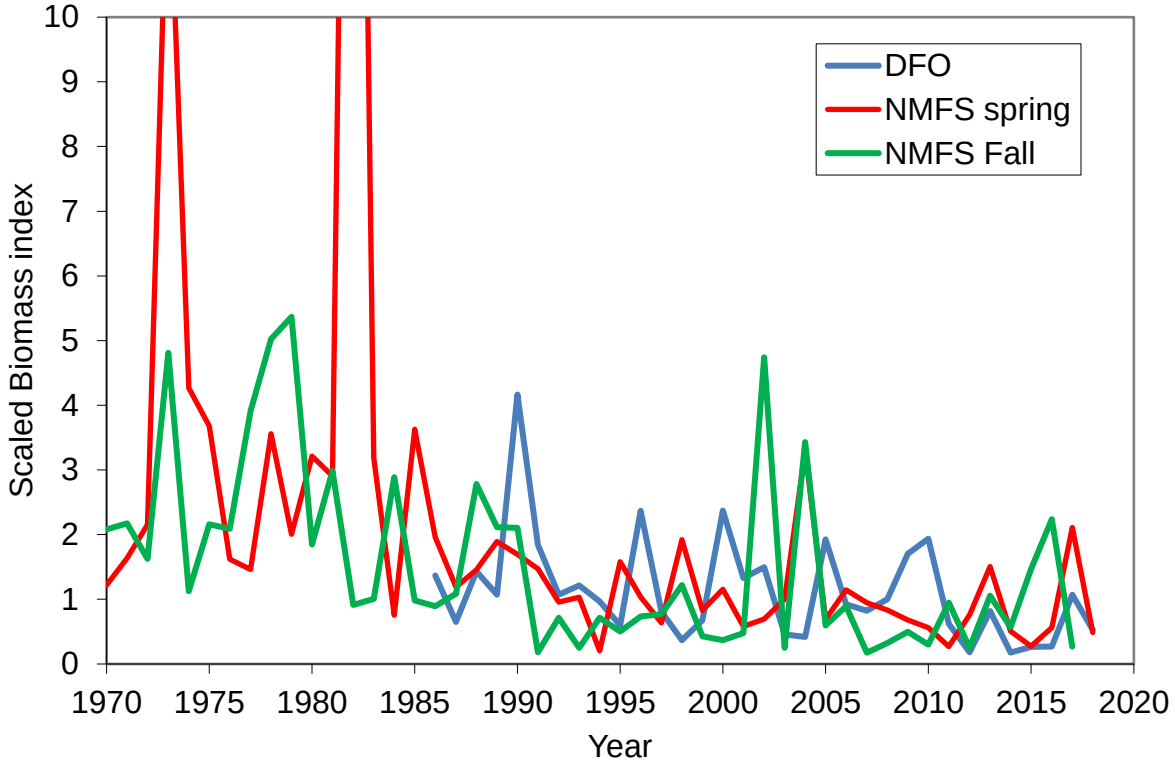

Figure 21. Survey biomass indices (ages 1+) for eastern Georges Bank cod from the DFO spring, NMFS spring and NMFS fall surveys scaled to their respective time series means from 1996 to 2017.

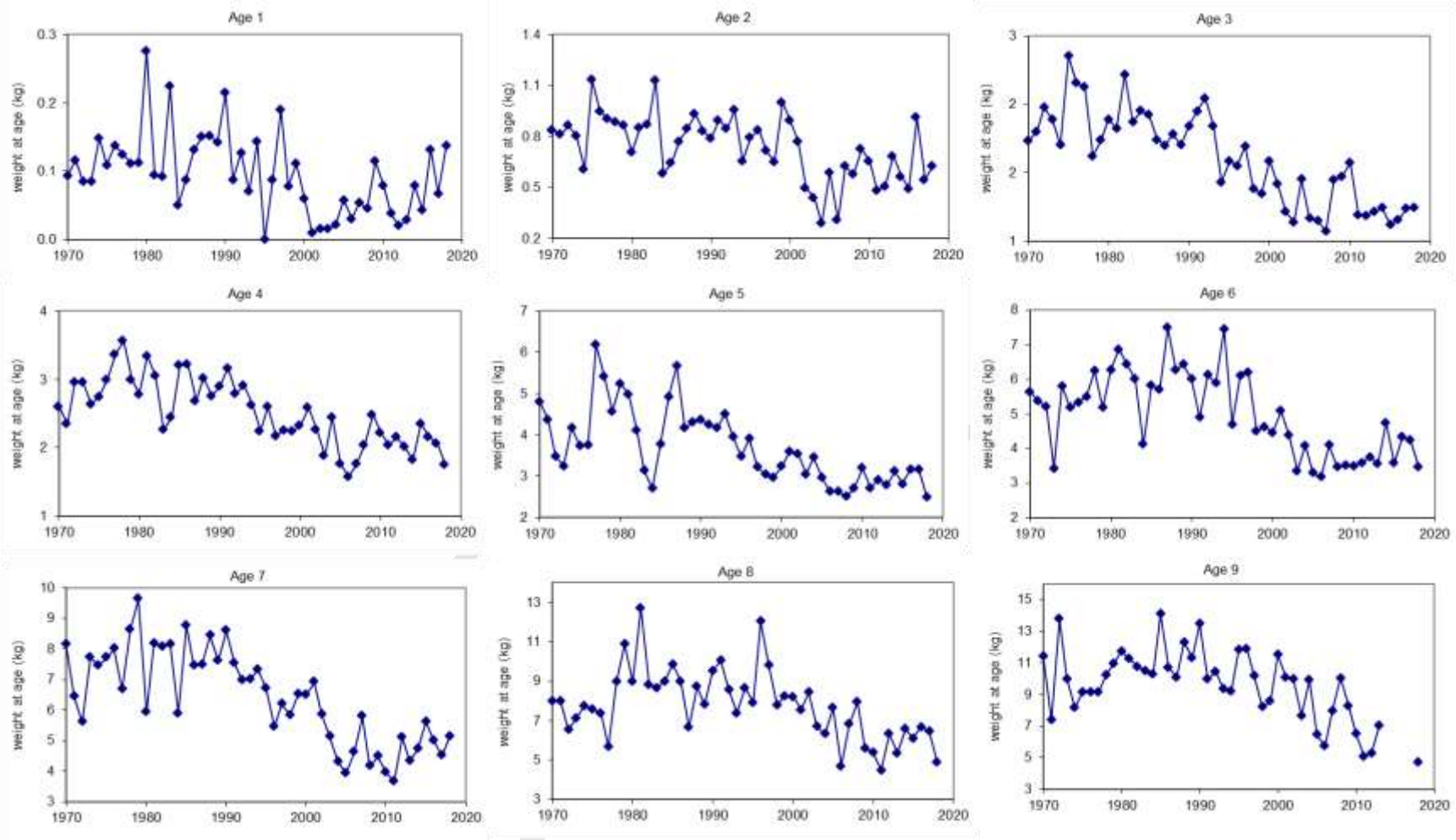

Figure 22. Beginning of year weight at age of eastern Georges Bank cod from DFO and NMFS spring surveys.

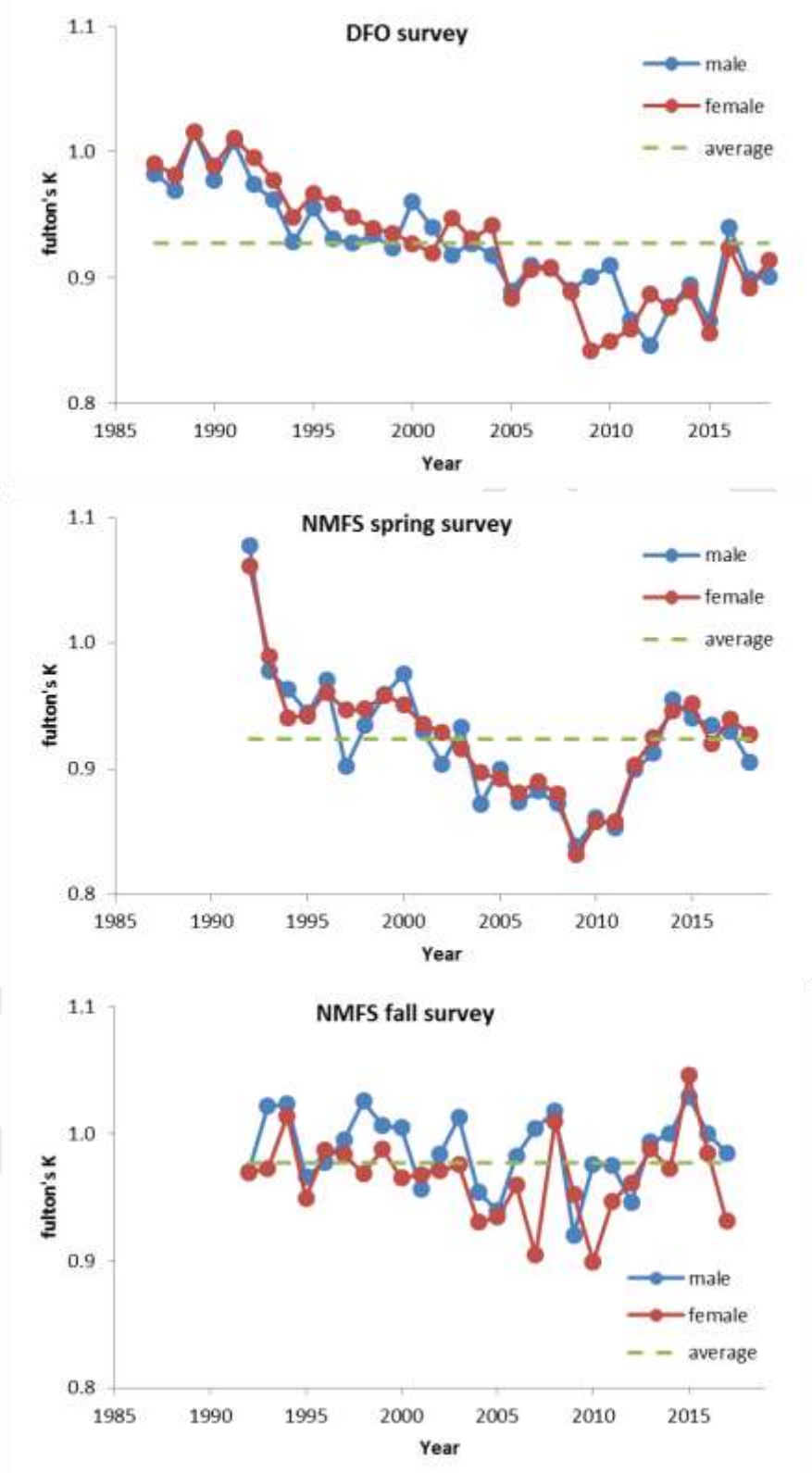

Figure 23. Fish condition (Fulton's K) of post-spawning cod for eastern Georges Bank.

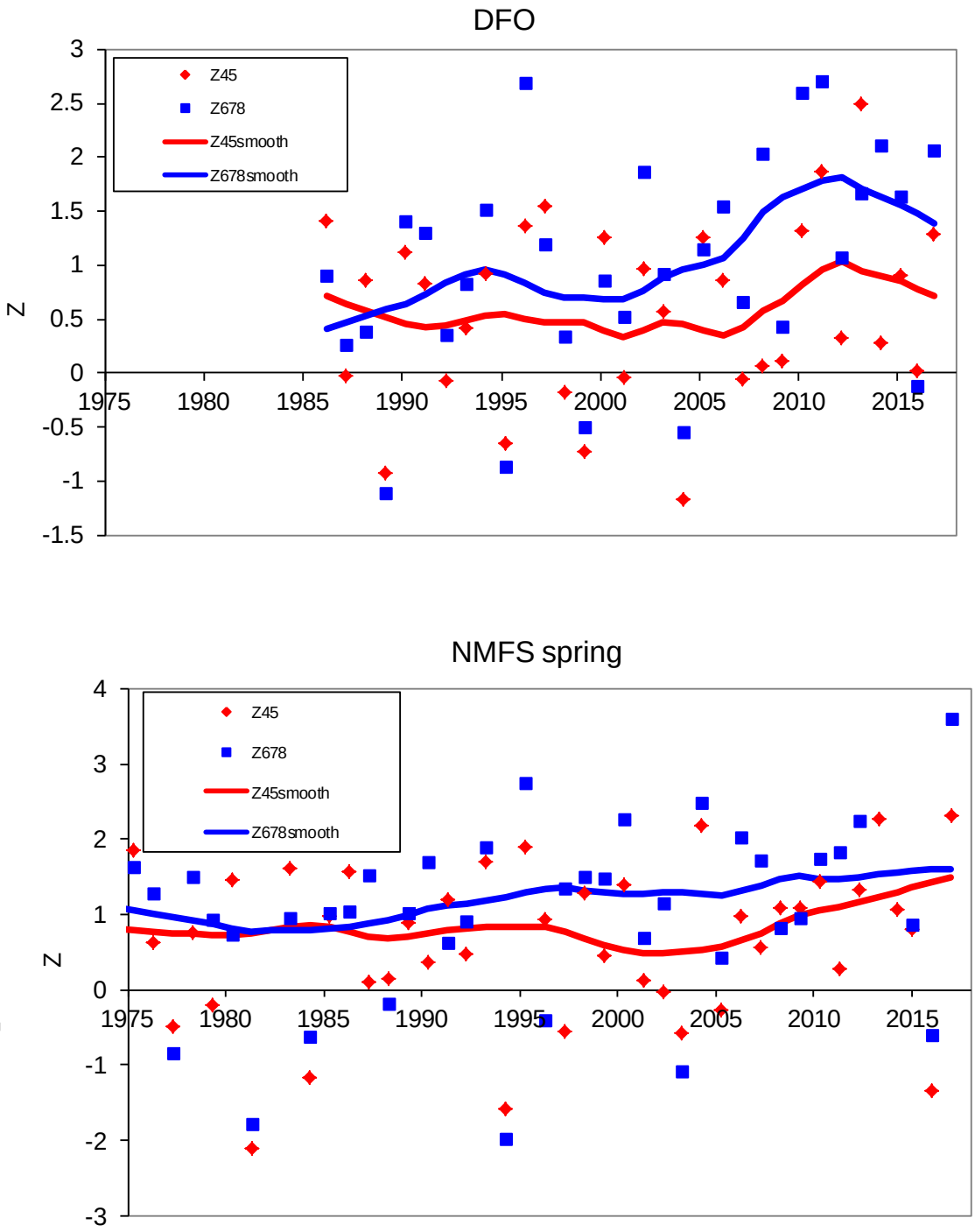

Figure 24. Total mortality(Z) calculated using the DFO and NMFS spring surveys data for eastern Georges Bank cod.

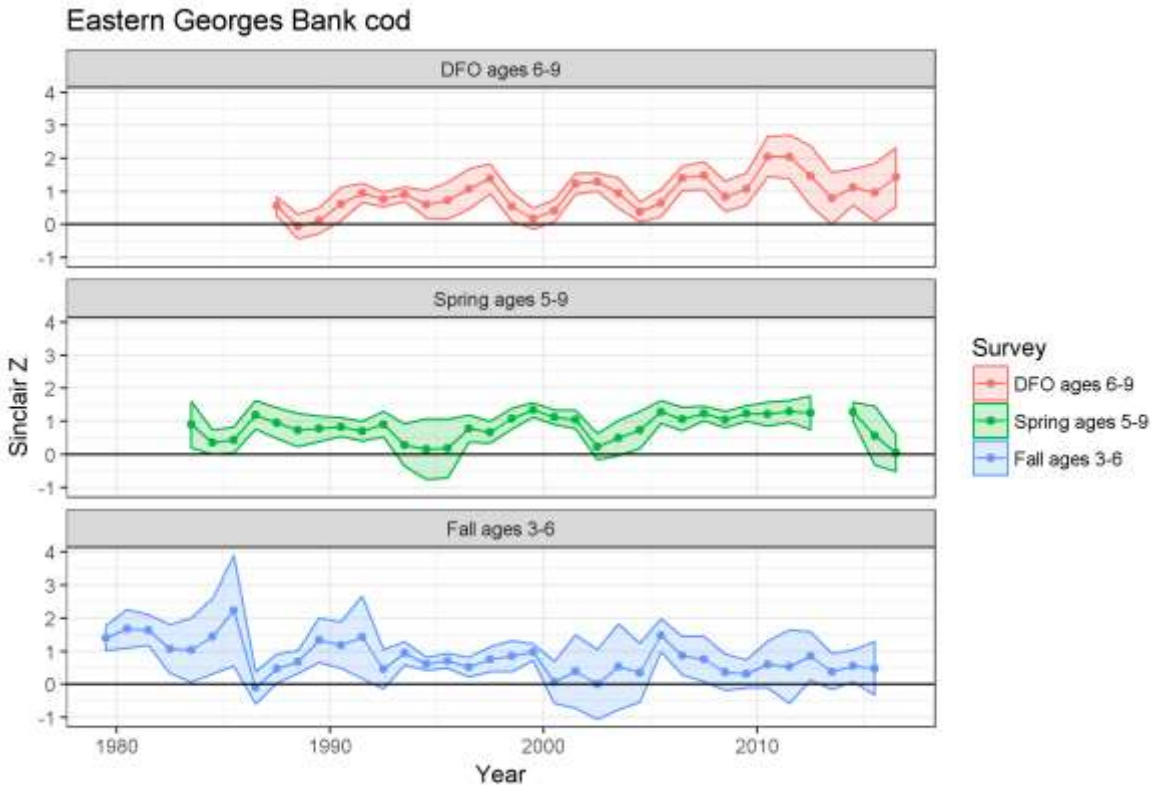

Figure 25. Empirical estimate of total mortality for the DFO (ages 6-9), NMFS spring (ages 5-9) and NMFS fall (ages 3-6) surveys.

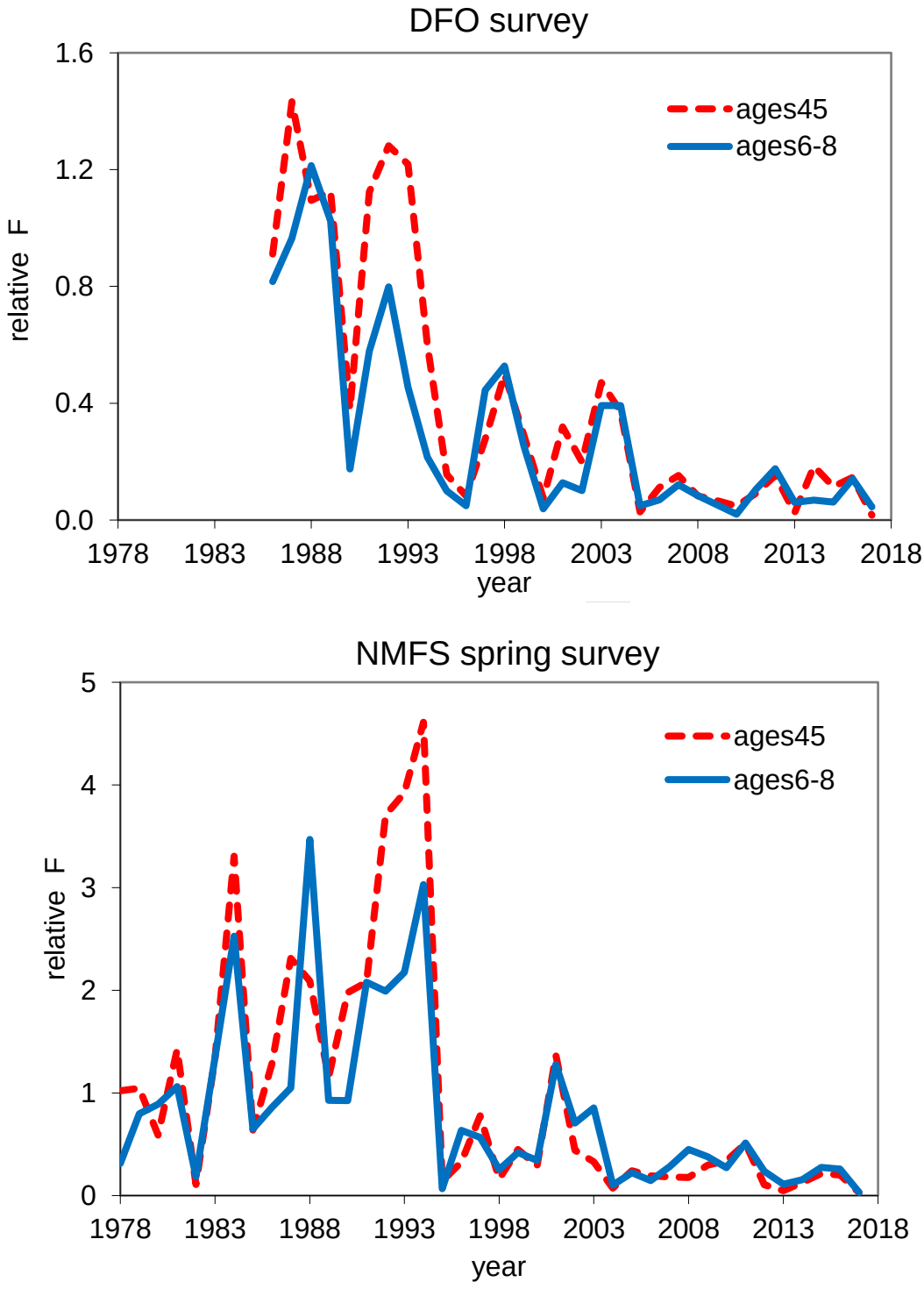

Figure 26. Relative F for eastern Georges Bank cod.

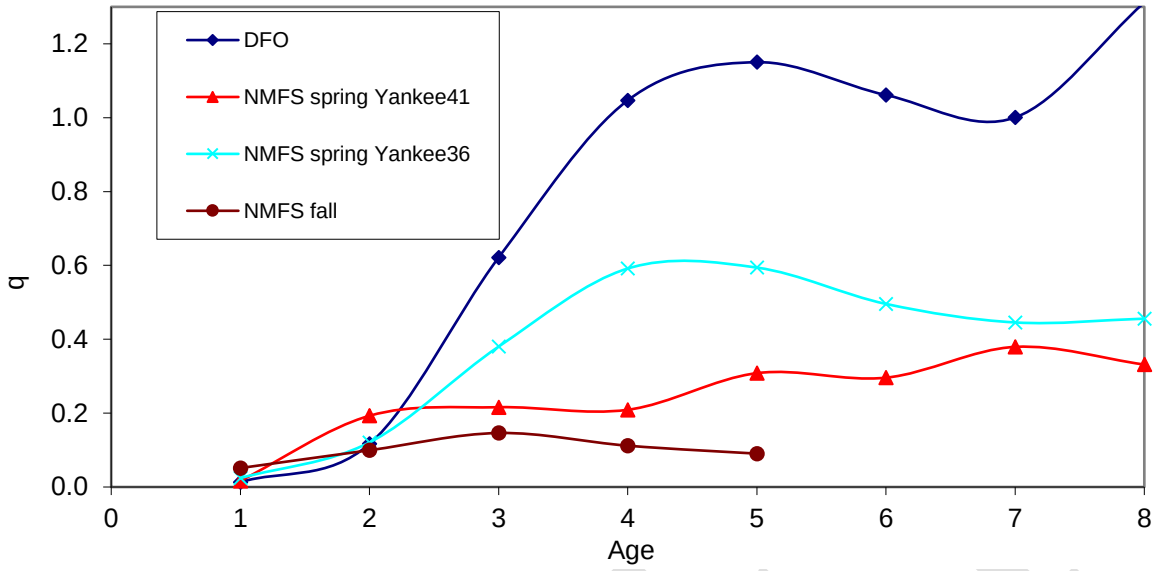

Figure 27. Survey catchability (q) of the DFO, NMFS spring and NMFS fall surveys for eastern Georges Bank cod.

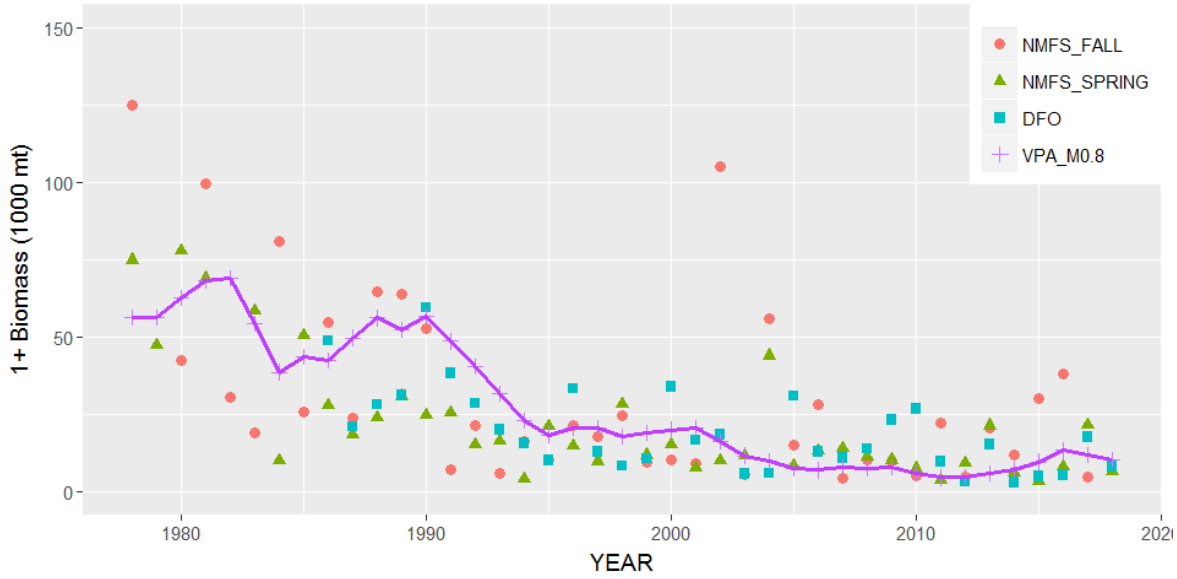

Figure 28. Q-adjusted age 1+ biomass from survey and 1+ biomass estimated from the VPA.

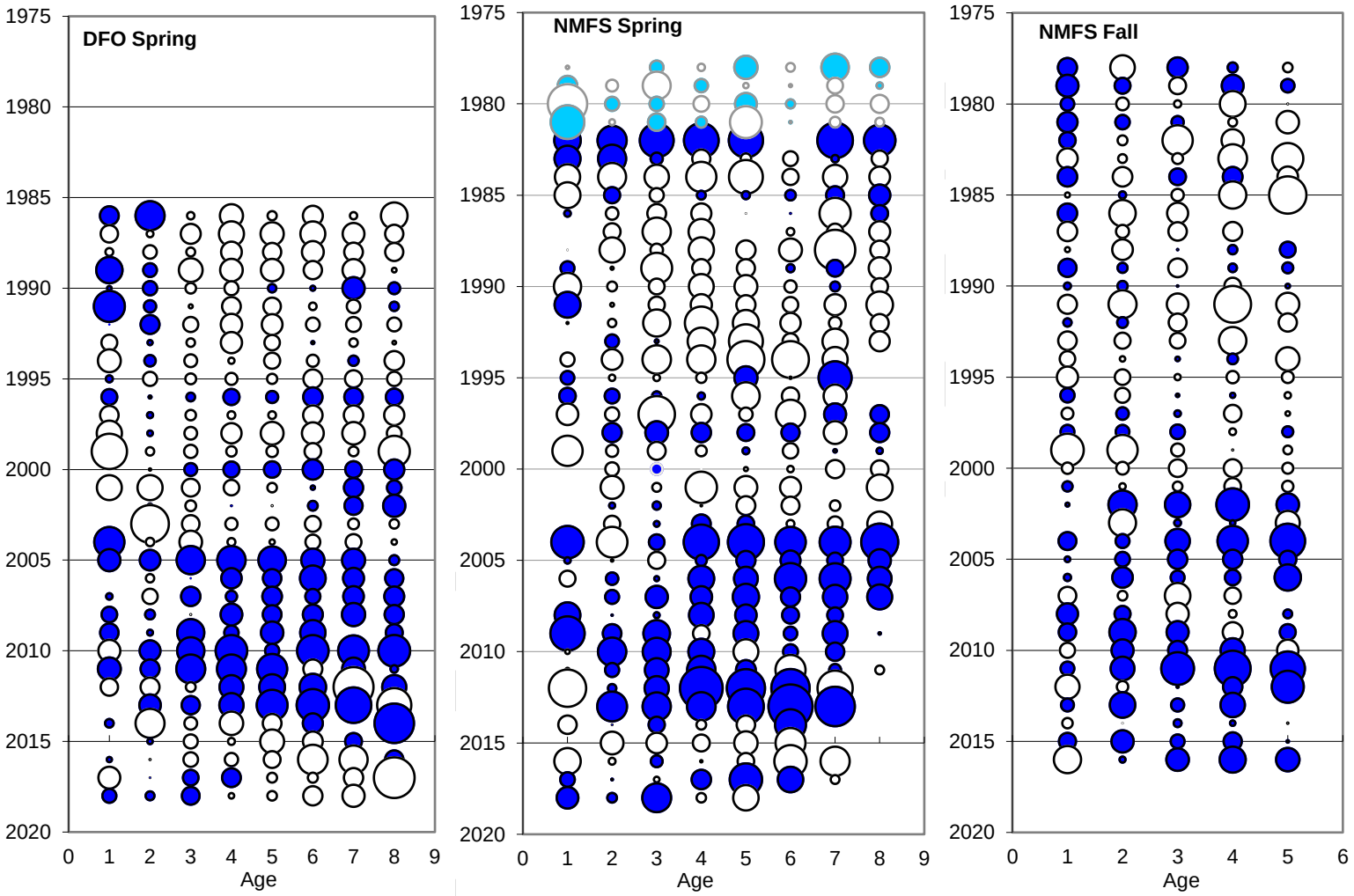

Figure 29. Residuals by year and age group from survey indices for eastern Georges Bank cod. Solid bubbles indicate positive values, open bubbles indicate negative values and the bubble area is proportional to magnitude. The NMFS spring survey was conducted using a modified Yankee 41 from 1978 to 1981 (light blue bubbles).

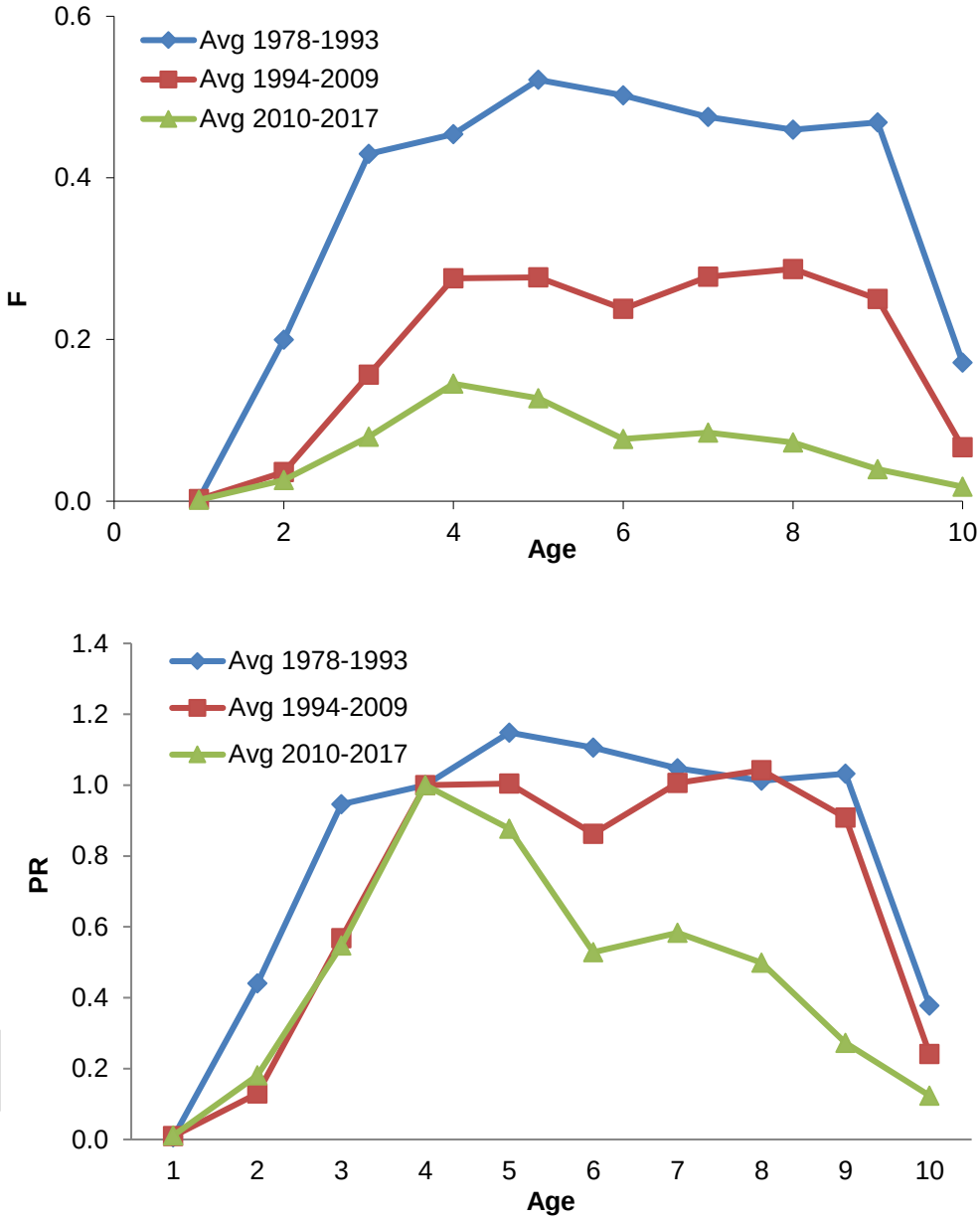

Figure 30. Average fishing mortality (F, upper panel) for eastern Georges Bank cod in three time series blocks (1978-1993, 1994-2009, 2010-2017).

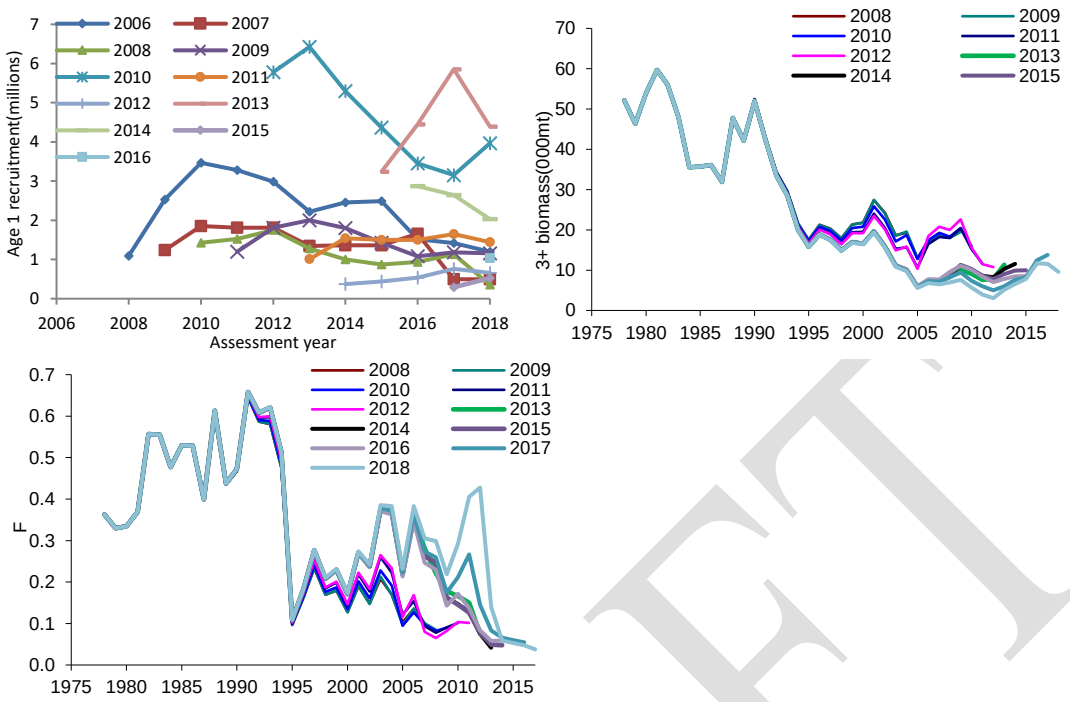

Figure 31. Retrospective patterns for recruitment at age 1, 3+ biomass and fishing mortality of eastern Georges Bank cod for the "M 0.8" model in 2018 assessment.

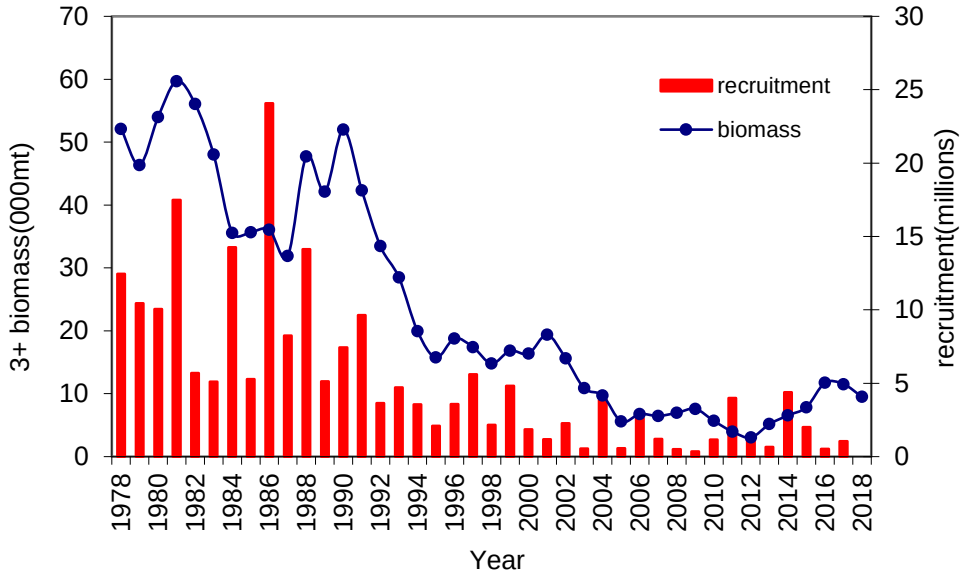

Figure 32. Adult biomass (ages 3+) and year class abundance at age 1 for eastern Georges Bank cod.

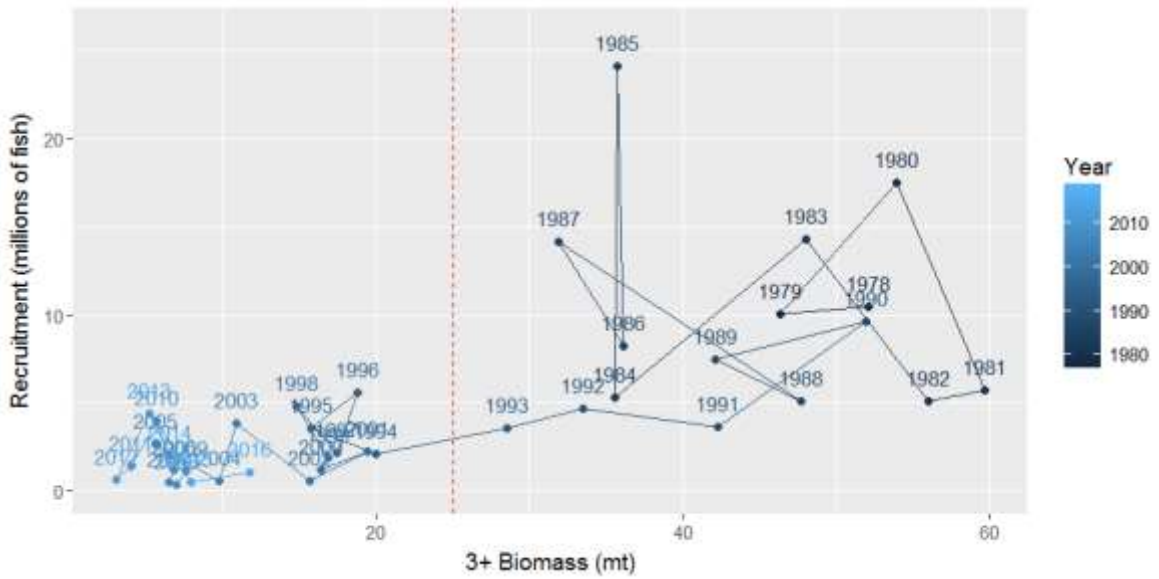

Figure 33. Relationship between adult biomass (ages 3+) and recruits at age 1 for eastern Georges Bank cod.

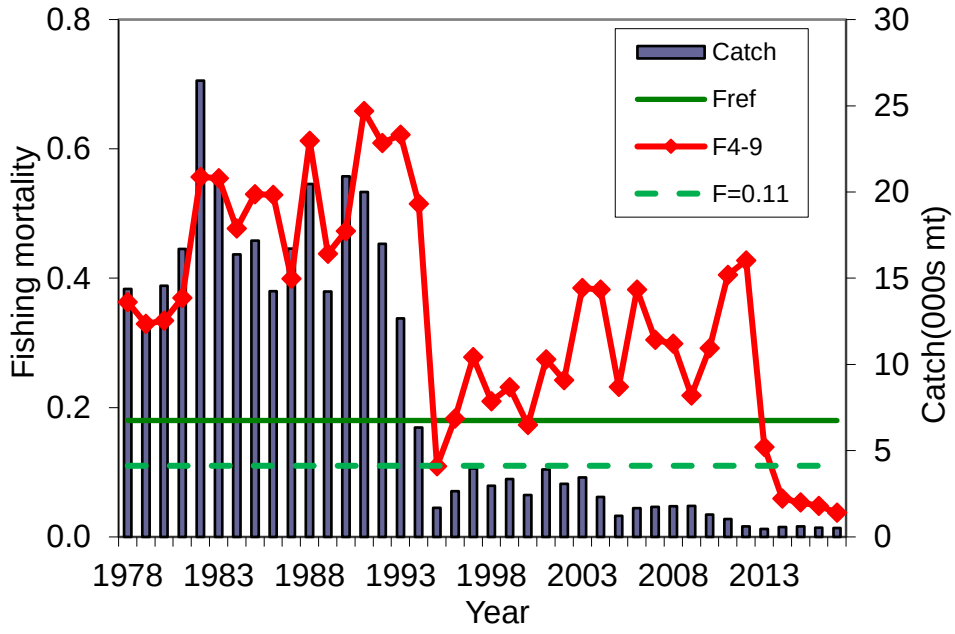

Figure 34. Average fishing mortality rate at ages 4 to 9 and catches for eastern Georges Bank cod. The established fishing mortality threshold reference, Fref=0.18. The F reference point for the "M 0.8" model is 0.11.

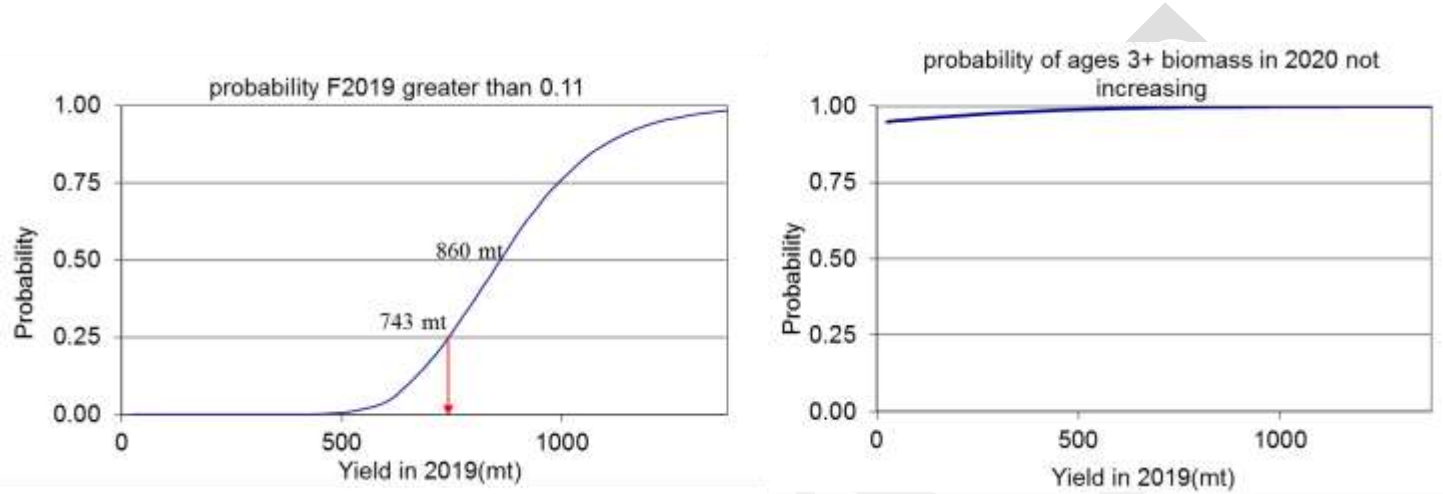

Figure 35. Risk of 2019 fishing mortality exceeding F reference point 0.11 and 2020 biomass not increasing from 2019 for alternative total yields of eastern Georges Bank cod from the "M 0.8" model formulation.

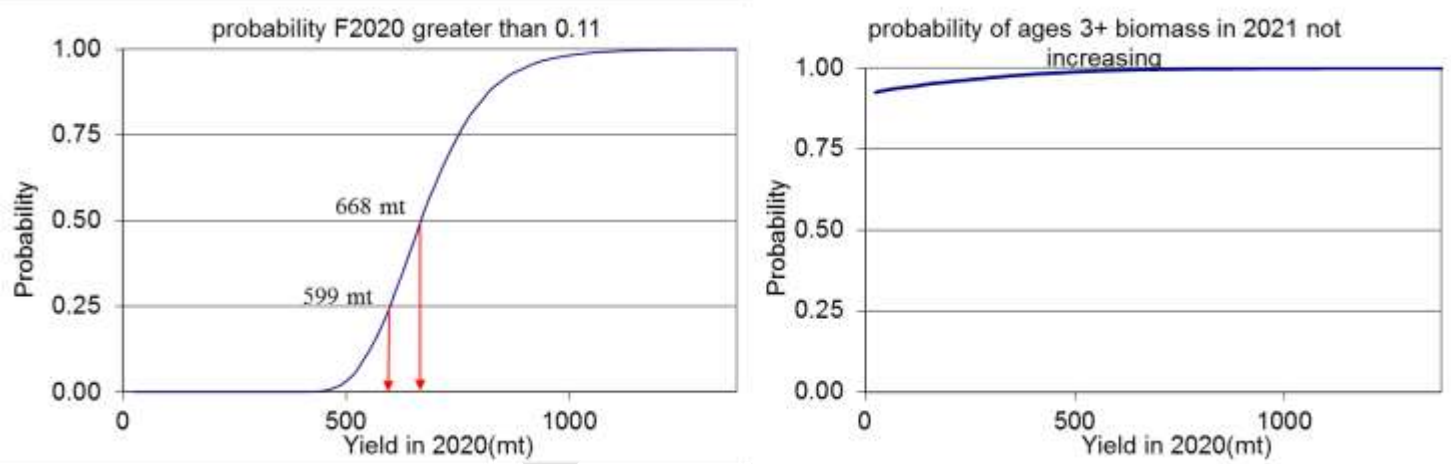

Figure 36. Assuming F2019=0.11, risk of 2019 fishing mortality exceeding F reference point 0.11 and 2021 biomass not increasing from 2020 for alternative total yields of eastern Georges Bank cod from the "M 0.8" model formulation.

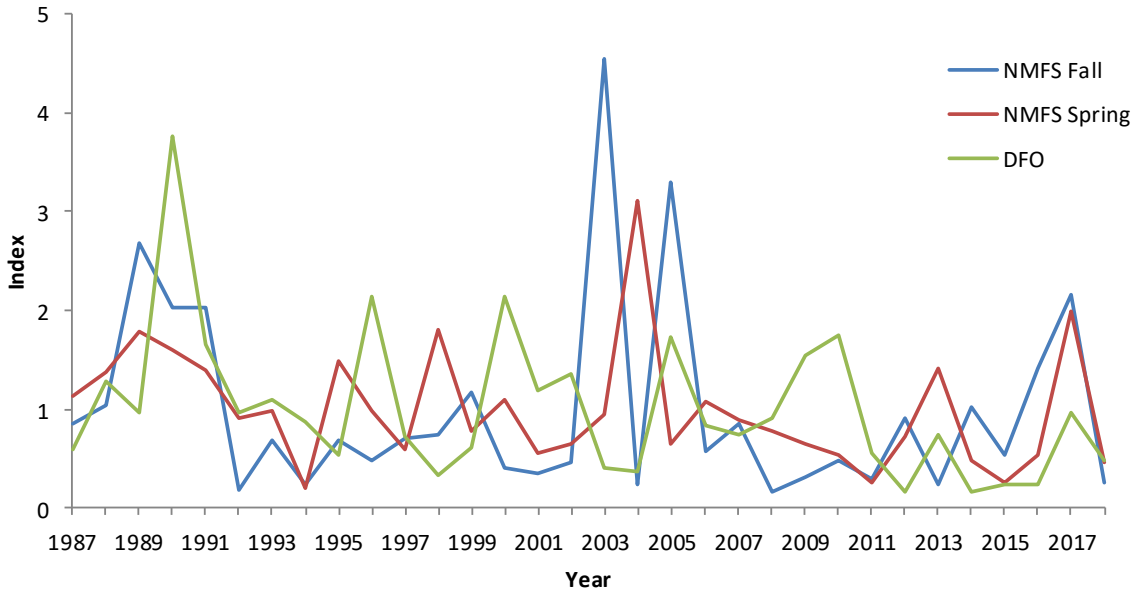

Figure 37. Plot of the normalized NMFS fall, DFO, and NMFS spring indices from 1987 (1986 fall) through 2018 (2017 fall). All three indices were divided by their mean and are plotted on the same scale.

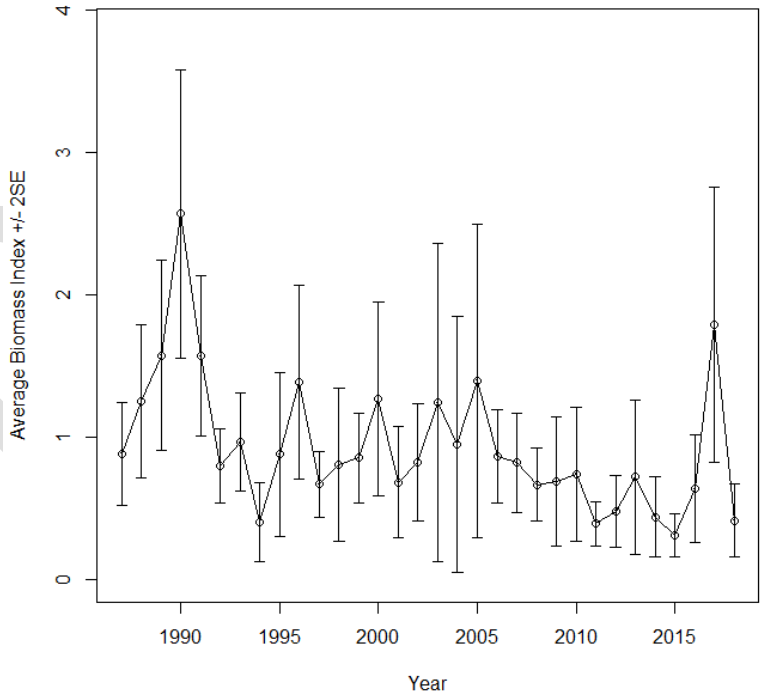

Figure 38. Plot of the combined index from CV weighted average of the three surveys (NMFS fall, DFO, and NMFS spring).

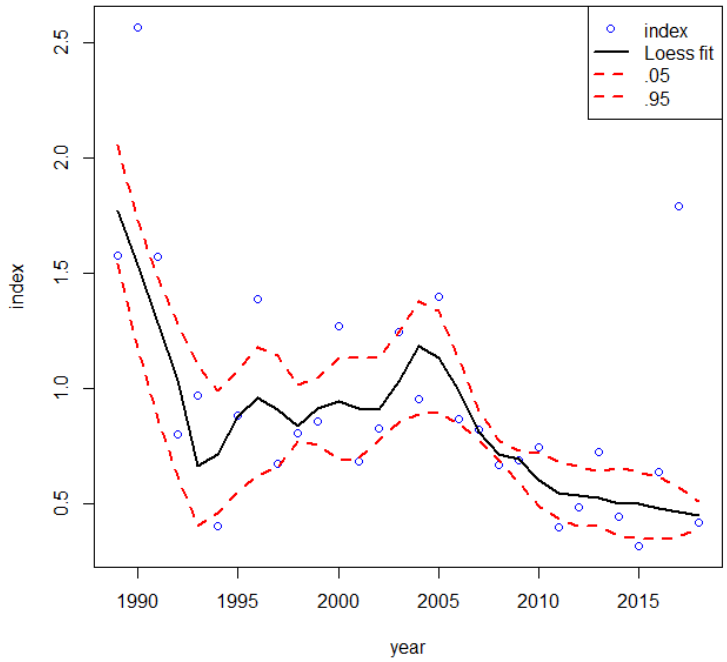

Figure 39. Model fits of survey biomass index using a robust least square loess smoother.

Figure 40. Bootstrap confidence intervals for the estimated slope of robust least squares.

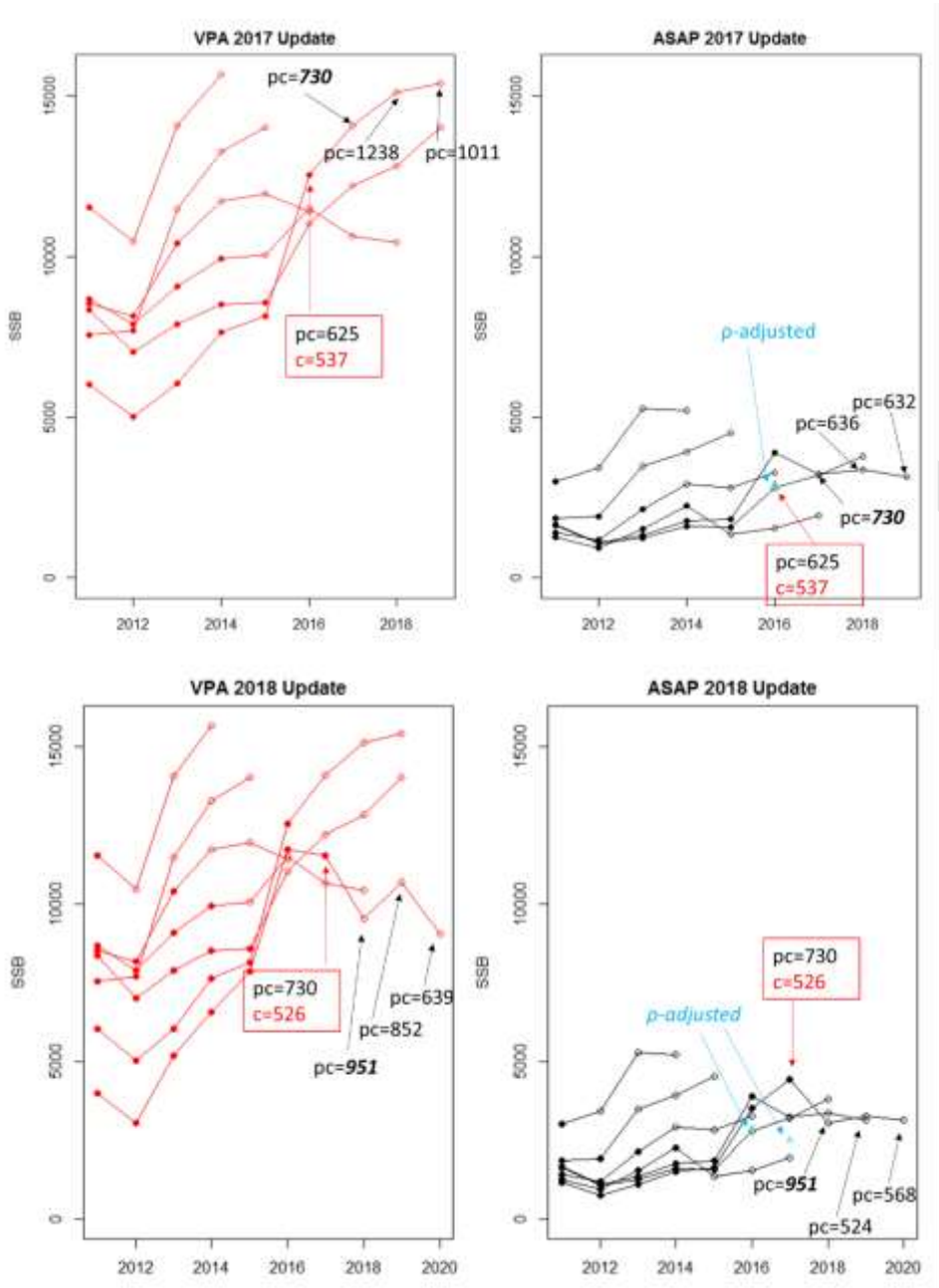

Figure 41. Deterministic projection results from VPA and ASAP models at TRAC 2017 (top) and TRAC 2018 (bottom). Solid circles indicate the last model estimate of adult biomass (SSB), open circles indicate projected SSB, light blue triangles are the 2017 SSB in ASAP adjusted for retrospective pattern. Projected catch amounts ("pc") are indicated for each year of removal; bold italic values are quotas that were agreed to previously, while non-bold values represent catch (mt) that results from applying F=0.11 (VPA) or F=0.18 (ASAP). In the red 'box,' the realized catch ("c") is indicated for comparison with the quota that had been assumed in the previous assessment projection.

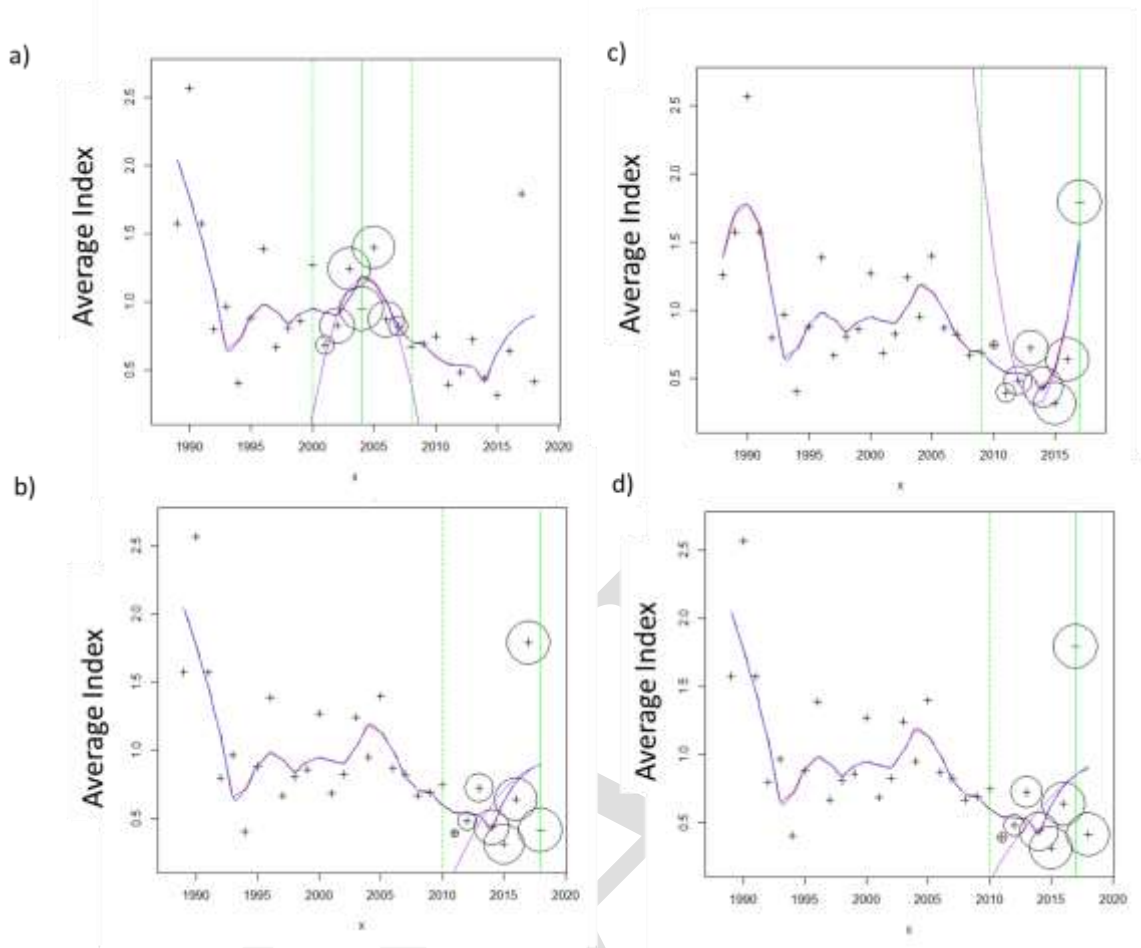

Figure 42. Illustration of data range (dashed green vertical lines) used to inform the fit at the location of the solid green vertical line. Data in the middle of the time series (a) uses a neighborhood of data on either side of the points being fitted, while data at the end of the time series (b, c) only have information to the left of the point being fitted. The fit to the 2017 observation changes from when 2017 is the terminal year (c) to when 2018 is the terminal year (d).

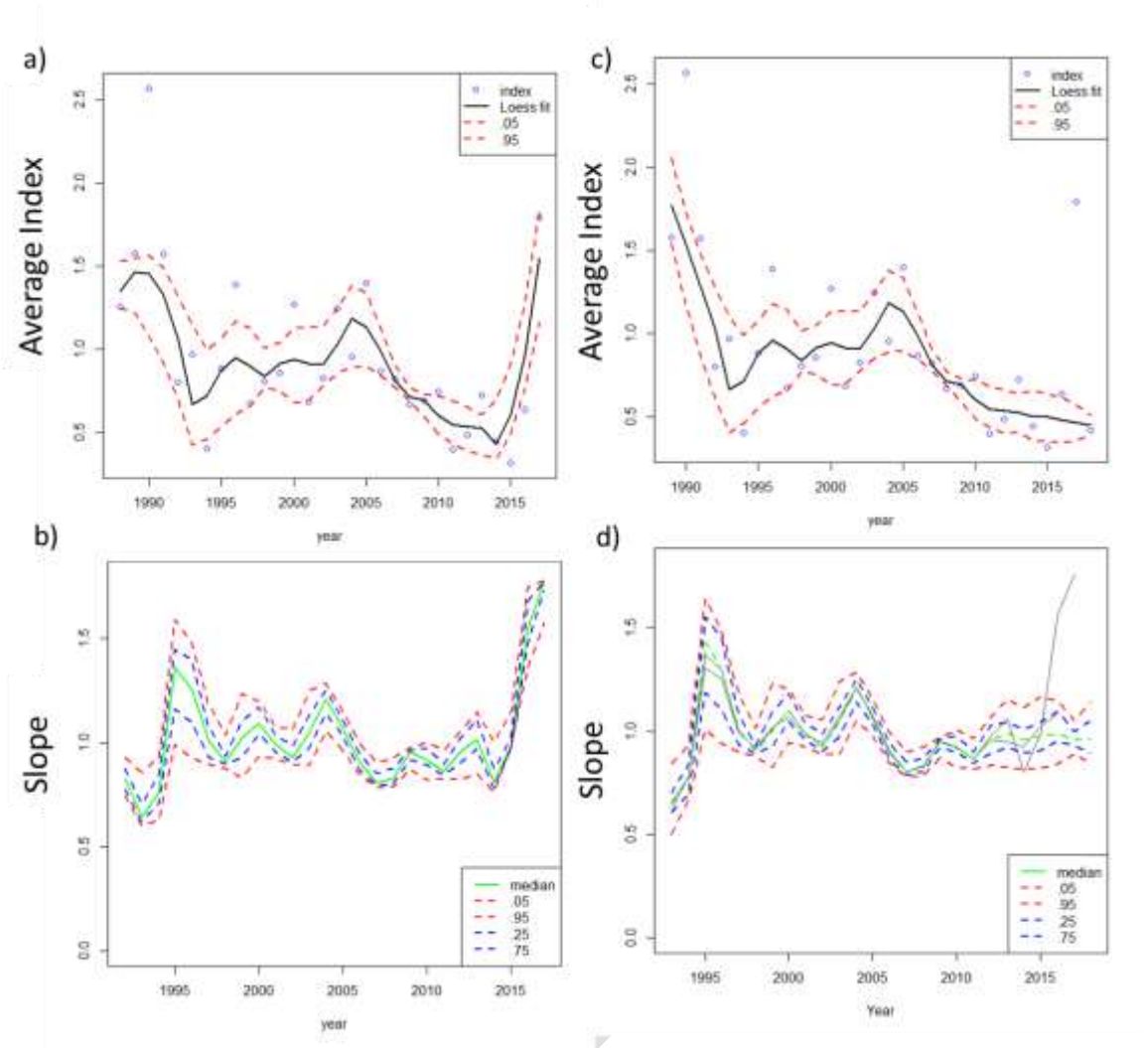

Figure 43. The loess fitted through 2017 (a) and the estimated slope from that fit (b), and the loess fitted through 2018 (c) and the estimated slope from that fit (d). Thin gray lines in (d) are a retrospective calculation of slopes based on removing 1-2 years of data (i.e. the 2016 and 2017 fits).

APPENDIX A: MANAGEMENT HISTORY OF EASTERN GEORGES BANK COD FISHERY (1978-2014)

a) Canadian fishery management history of cod on eastern Georges Bank, 1978 to 2016.

Year	Canadian Management History
1978	Foreign fleets were excluded from the 200 mile exclusive economic zones of Canada and USA.
1984	October implementation of the maritime boundary between the USA and Canada in the Gulf of Maine Area.
1985	5Z cod assessment started in Canada; Set TAC; TAC=25,000mt
1986	TAC=11,000mt
1987	TAC=12,500mt
1988	TAC=12,500mt
1989	TAC=8,000mt; 5Zjm cod assessment.
1990	Changes to larger and square mesh size; Changes from TAC to individual and equal boat quotas of 280,000lb with bycatch restrictions; Temporary Vessel Replacement Program was introduced.
1991	TAC=15,000mt; Dockside monitoring; Maximum individual quota holdings increased to 2% or 600t (whichever was less).
1992	TAC=15,000mt Introduction of ITQs for the OTB fleet.
1993	TAC=15,000mt, ITQ for the OTB fleet not based on recommended catch quotas; OTB <65 fleet was allowed to fish during the spawning season (Mar.–May. 31).
1994	TAC=6,000mt, Spawning closures January to May 31; Mesh size was 130mm square for cod, haddock an Pollock for ITQ fleet; Minimum mesh size of 6" was required for gillnets; Minimum fish size is 43cm (small fish protocols) for cod, haddock an Pollock for ITQ fleet; OT> 65' could not begin fishing until July 1; Fixed gear must choose to fish either 5Z or 4X during June 1 to September 30.
1995	TAC=1,000mt as a bycatch fishery; January 1 to June 18 was closed to all groundfish fishery; 130mm square mesh size for all mobile fleets; Small fish protocols continued; 100% dock side monitoring; Fixed gear vessels with a history since 1990 of 25mt or more for 3 years of cod, Haddock, Pollock, hake or Cusk combined can participate in 5Z fishery.
1996	TAC=2,000mt; Prohibition of the landing of groundfish (except monkfish) by the scallop fishery; ITQ vessel require minimum 130mm square mesh for directed cod, Haddock and Pollock trips; Small fish protocols continued; For community management, quota allocation of each fixed gear based on catch history using the years 1986-1993; 100% mandatory dockside monitoring and weighout.
1997	TAC=3,000mt
1998	TAC=1,900mt
1999	TAC=1,800mt; Mandatory cod separator panel when no observer on board; Jan. and Feb. mobile gear winter Pollock fishery.
2000	TAC=1,600mt; Jan. and Feb. mobile gear winter Pollock fishery.
2001	TAC=2,100mt
2002	TAC=1,192mt
2003	TAC=1,301mt
2004	TAC=1,000mt; Canada-USA resource sharing agreement on Georges Bank.

Year	Canadian Management History
2005	TAC=740mt; Exploratory winter fishery Jan. to Feb. 18, 2005; Spawning protocol: 25% of maturity stages at 5 and 6.
2006	TAC=1,326mt; Exploratory winter fishery Jan. to Feb.6, 2006; Spawning protocol: 30% of maturity stages at 5 to 7.
2007	TAC=1,406mt; Exploratory winter fishery Jan. to Feb. 15, 2007; High mobile gear observer coverage (99%); Spawning protocol: 30% of maturity stages at 5 to 7.
2008	TAC=1,633mt; Winter fishery from Jan.1 to Feb. 8, 2009; At sea observer coverage 38% by weight of the mobile gear fleet landings and 21% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2009	TAC=1,173mt; Winter fishery from Jan. 1 to Feb. 21, 2009; At sea observer coverage 23% by weight of the mobile gear fleet landings and 15% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2010	TAC=1,350mt; Winter fishery from Jan. 1 to Feb. 8, 2010; At sea observer coverage 18% by weight of the mobile gear fleet landings and 6% by weight of the fixed gear landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2011	TAC=1,050mt; Winter fishery from Jan. 1 to Feb. 5, 2011; At sea observer coverage 19% by weight of the mobile gear fleet landings, 20% by weight of the fixed gear landings and 3% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2012	TAC=513mt; Winter fishery from Jan. 1 to Feb. 6, 2012; At sea observer coverage 42% by weight of the mobile gear fleet landings, 26 % by weight of the fixed gear landings and 35% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2013	TAC=504mt; Winter fishery from Jan. 1 to Feb. 3, 2013; At sea observer coverage 78% by weight of the mobile gear fleet landings, 29%by weight of the fixed gear landings and 19% by weight of the gillnet fleet landings; Spawning protocol: 30% of maturity stages at 5 to 7.
2014	TAC=546mt; Winter fishery from Jan. 1 to Feb. 9, 2014; A test project with alternative codend meshes of 125mm square and 145 diamond for the purpose of improving the catch rate of haddock and reducing cod bycatch relative to haddock catches; At sea observer coverage 60% by weight of the mobile gear fleet landings, 45%by weight of the fixed gear landings and 14% by weight of the gillnet fleet landings Spawning protocol: 30% of maturity stages at 5 to 7.
2015	TAC=650mt; Winter fishery from Jan. 1 to Feb 2, 2015; Based on results of the 2014 test project 125mm square mesh was approved for use in 2015 and 2016. At sea observer coverage 75% by weight of the mobile gear fleet landings, 33%by weight of the fixed gear landings and 11% by weight of the gillnet fleet landings Spawning protocol: 30% of maturity stages at 5 to 7.
2016	TAC=730 Winter fishery from Jan. 1 to Feb. 7, 2016. Based on results of the 2014 test project 125mm square mesh was approved for use in 2016. At sea observer coverage was 67% by weight for the mobile gear fleet, 21% by weight for fixed gear and 4% by weight for gillnet fleet landings. Spawning protocol: 30% of maturity stages at 5 to 7.

b) USA fishery management history of cod on eastern Georges Bank, 1978 to 2016.

Year	Regulatory Actions
1953	ICNAF era
1973-1986	TAC implemented for Div 5Zcod; 35,000/year
1977	Groundfish Fishery Management Plan (FMP) Magnuson-Stevesn Conservation Management Act (MSCMA)
1982	Interim FMP
1984	Hague Line implemented
1985	Multi-species FMP
1989	Amendment 2
1994	Emergency Rule - December Year round closures in effect
1994	Amendment 5; Days at Sea (DAS) monitoring ; Mandatory reporting : Vessel Trip Reports (VTR)
	Amendment 6
1996	Amendment 7; accelerated DAS reduction
	Sustainable Fisheries Act (SFA)
1999	Amendment 9
2002	Interim rule ; 20 % reduction in DAS
2004	Amendment 13; further reduction in DAS; hard TAC on EGB haddock and cod
	Eastern US/CA Area haddock Special Access Program (SAP) Pilot Progam
2005	DAS vessels limited to one trip/month in Eastern US/CA Area until April 30;
	Limited accesss DAS vessels required to use separator panel trawl in the area
2006	Haddock separator trawl or flounder net required in Eastern US/CA area
2008	Sept - Ruhle trawl (eliminator trawl) allowed in Eastern US/CA area
2009	Nov- Eastern US/CA area , trawl vessels requried to use separator/Ruhle south 41-40N
2010	Amendment 16, Framwork 44 implemented; Sector management ;
	US/CA area:prohibition on discarding legal size fish
	Common pool: 500 lbs/day, 5,000 lbs/trip
2012	US/CA area open May 1 for trawl gear: haddock separator, rhule or flounder trawl
2015-16	Inside US/CA GB cod: common pool : 100 lb/DAS , 500 lb/trip
	Inside US/CA GB cod: common pool : 100 lb/DAS , 500 lb/trip
	Common pool may fish inside US/CA area uing haddock sparatore trawl, Ruhle trawl, or flounder net
2016	May 1: sectors allowed to convert eGB allocation into western GB cod allocation during FY, and 2 weeks into new fishing year to cover any overage during previous FY
	Mesh Sizes (inches)
1953	4.5
1977	5.125
1983	5.5
1987	6.0
1989	eliminate 6 inch increase
1994	6.0
1999	6.5 square mesh/ 6.0 diamond mesh
2000	6.5 square mesh/ 6.5 diamond mesh
2002	6.5 square mesh/ 6.5 diamond mesh/6.5 gill net
	Minimum Size
1977	16 inches(40.6 cm) commercial and recreational
1982	17 inches (43.2 cm) commercial; 15 inches (38.1 cm) recreational
1986	19 inches (48.3 cm) commercial; 17 inches (43.2 cm) recreational
1988	19 inches (48.3 cm) commecial and recreational
1997	21 inches (53.3) recreational
2002	22 inches (55.9 cm) commercial; 23 inches (58.4 cm) recreational
2003	21 inches (53.3 cm) recreational
2013	19 inches (48.3 cm) commercial, July start

Year	Trip Limits
2004	GB cod: 1,000 lbs/day, 10,000 lbs/trip; EGB: hard TAC on cod
	500 lbs/day, 5,000 lbs/trip in Eastern US/CA area
2005	500 lbs/day, 5,000 lbs/trip in Eastern US/CA area
	Starting July, one trip/month in Eastern US/CA area until Apr. 30, 2006
2006	500 lbs/day, 5,000 lbs/trip in Eastern US/CA area
2007	1,000 lbs/trip of cod in Eastern US/CA area or Haddock SAP
2008	1,000 lbs/trip of cod in Eastern US/CA area fishing EGB exclusively
2009	Mar-500 lbs/trip of cod in Eastern US/CA area; back to 1,000 in April
2010	Gb Cod: 2,000 lbs/day, 20,000 lbs/trip; EGB cod: 500 lbs/day, 5,000 lbs/trip
2011	Mar-3,000 lbs/day during April
	500 lbs/day after April in EGB area
2012	Common pool: GB cod 1,500 lbs/A DAS up to 4,500 lbs/trip
	Handgear B 75 lbs/trip
2013	Jan1: Common pool: GB cod 3,000 lbs/A DAS up to 30,000 lbs/trip
	Handgear B 125 lbs/trip
	May 1: Handgear A 300 lbs/trip; handgear B 75 lbs/trip
2014	Common pool: GB cod 2,000 lbs/DAS, up to 20,000 lbs/trip
2015	Common pool: EGB cod 100 lbs/DAS, up to 500 lbs/trip
2016	Common pool: EGB cod 100 lbs/DAS, up to 500 lbs/trip
	Closures
1970	Area 1(A) and 2(B) Mar-Apr
1972-1974	Area 1(A) and 2(B) Mar-May
1977	Seasonal spawning closure
1987	Modify closed area I to overlap with haddock spawning area
1994	Jan CA II expanded, closed Jan-May, CA I closed to all vessels except sink gillnet
	Dec. CA I and II closed year round to all vessels
1999	Scallopers allowed limited access to CA II
2004	May to Dec. access to northern corner of CA II & adjacent area to target haddock w/ separator trawl
	Oct - EGB area closed to multispecies DAS permits
2005	Jan - Eastern US/CA area reopened
	Apr - Eastern US/CA area closed until April 30
	Aug - Eastern US/CA area closed (GB cod TAC projected near 90%)
2006	Eastern US/CA haddock SAP delayed opening until Aug. 1
2007	April 25 - Eastern US/CA area closed until April 30
	Jun - Eastern US/CA area closed to limited access multispecies TAC (due to cod catch)
	Oct - Eastern US/CA area open to limited access multispecies TAC until Nov 30
	Dec - Eastern US/CA area closes
2008	May - Eastern US/CA area delayed opening until Aug. 1
	Jun - Eastern US/CaA area delayed opening until Aug. 1 for all gear (prevent catching 1st qtr cod TAC)
2009	Apr 16 - Eastern US/CA area closed; May - Eastern US/CA carea closed until Aug. 1 for trawl vessels
2010	Eastern US/CA area closed Apr 20-30, TAC harvested; May 1 opening delayed until August
2011	Eastern US/CA area closed from May - Jul for trawl gear (common pool vessels only)
2013	Common pool closure: July 30 - Aug 31 for GB cod
2014	Common pool closure: August 27 - April 30 for EGB cod
	Common pool closure: August 18 thru April 30, 2015 for GB cod
2017	Common pool closure: January 9 - April 30 for GB cod

APPENDIX B

2017 Statistical Catch at Age (ASAP) Model Update for Eastern Georges Bank Atlantic Cod

Introduction

This assessment presents an update of the statistical catch at age model 'Age Structured Assessment Program' (ASAP) reviewed at the 2013 April eastern Georges Bank cod management unit benchmark model meeting. No model was chosen by the TRAC as a benchmark model for stock status, however, the TRAC agreed (Claytor and O'Brien 2013) to use the VPA model results for catch advice with the ASAP model results in a consequence analysis (Appendix B) of projection results to be provided to managers for catch advice.

The ASAP model provided estimates of instantaneous fishing mortality and stock size in 2017. A retrospective analysis was performed for terminal year fishing mortality, spawning stock biomass, and age 1 recruitment. Stochastic projections from model results provide estimated landings and spawning stock biomass (SSB) in 2019-2020.

Assessment Model Formulation

Model description

ASAP, a forward projecting statistical catch at age model (Legault and Restrepo 1998) was applied in this assessment and can be downloaded from the NOAA Fisheries Toolbox (NFT, http://nft.nefsc.noaa.gov/). A brief description of the model can be found in a previous assessment (Wang et al. 2015) and for further details, the reader is referred to the technical manual (Legault 2008).

Data input

Input to the ASAP model is the same as for the VPA 0.8 model, with two exceptions. The ASAP uses beginning year weight-at-age that is back-calculated from the mid-year catch weight-at-age (Rivard 1982; Appendix. Table 1) rather than using the weight estimated from an average of the DFO and NEFSC spring research survey weight-at-age (Table 17). The ASAP also does not use the most recent terminal year +1 surveys (e.g.DFO 2018 and NEFSC 2018). The annual CVs for the surveys are increased to account for process error and to make a model that is more self-consistent (DFO +0.25, NMFS spring +0.30, NMFS spring +0.20).

Natural mortality (M) was age and time invariant and assumed to be 0.2 , which was also applied in earlier assessment models for cod from eastern Georges Bank (Wang and O'Brien 2012).

Model formulation

The ASAP benchmark model formulation (Andrushchenko et al. 2016) was updated for the 2018 assessment.

Model Results

Terminal year (2017) estimates of SSB and F, Mohn's rho for SSB and F, and retrospective adjusted values of SSB and F show the strong influence of applying the retrospective adjustment (Appendix Table 2).

Model diagnostics are very similar to last years' assessment (Martin et al. 2017). Model fit to total catch indicates generally lower predicted catch prior to 1995 and generally higher predicted catch from 1995 onward (Appendix Figure 1). Patterns in residuals still persist in both the catch and in the surveys, (Appendix Figures 2- 8). The effective sample size (ESS) for the catch and surveys is still appropriate.

Fishing mortality, SSB, and recruitment

Fully recruited F (unweighted, ages 5-8) was estimated at 0.13 in 2017 (Appendix Table 3, Appendix Figure 9), a 46% decrease from 2016. SSB in 2017 was estimated at 4,417 mt, a 26% increase from 2016 (Appendix Table 3, Appendix Figure 9). Recruitment (millions of age 1 fish) of the 2016 year class is estimated at 1.380 million. The 2013 year class is estimated at 2.233 million fish, the largest year class since the 2003 year class, now estimated at 2.418 million age 1 fish (Appendix Table 3, Appendix Figures 9-10).

Retrospective analysis

A retrospective analysis was performed to evaluate how well the ASAP calibration would have estimated F, SSB, and recruits at age 1 for seven years (2010-2016) prior to the terminal year, 2017. The pattern of overestimating SSB and underestimating F relative to the terminal year persists in this assessment, and there is a general pattern of underestimating recruitment relative to the terminal year estimate (Appendix Figure 11). The retrospective rho values, the average of the last 7 years of the relative retrospective peels, were 0.76 for SSB, -0.41 for F_{5+}, and -0.31 for recruitment. Since the retrospective adjusted values of SSB and F are outside the 90% probability intervals (see below), the model results need to be adjusted for retrospective bias (Figure 12).

Biological Reference Points

The current negotiated eastern Georges Bank cod fishing mortality reference point is F_{ref} =0.18 (TMGC 2002).

Projections

Short term stochastic projections under F_{ref} =0.18 were performed from the 2018 ASAP model results to estimate landings and SSB during 2019-2020. The input values for mean catch and stock weights, partial recruitment (PR), and maturity were estimated as 3-year averages from 2015-2017. Recruitment was estimated from a 2-stage cumulative distribution function (CDF) based on either 25 low estimates or 14 high estimates of age 1 recruitment. Based on a visual examination of the stock recruit plot (Appendix Figure 10), a cut-point of 15,000 mt was established, such that, when SSB is less than 15,000 mt, recruitment is drawn from the low recruitment CDF, and when SSB is greater than 15,000 mt, recruitment is drawn from the high recruitment CDF. Catch in 2018 was estimated based on the assumption that the 2018 quota of 951 mt would be caught.

The results of the short term projections indicate under F_{ref} = 0.18, catch is projected to decrease in 2018 and remain low in 2019. SSB is projected to increase in 2019 and decrease in 2020.

Year	SSB	F	Catch
2018	3047	0.35	951
2019	3281	0.18	524
2020	3142	0.18	568

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Appendix. Table 1. January 1 catch weight-at-age (kg) for ages 1-10+, for eastern Georges Bank cod, 1978-2017.

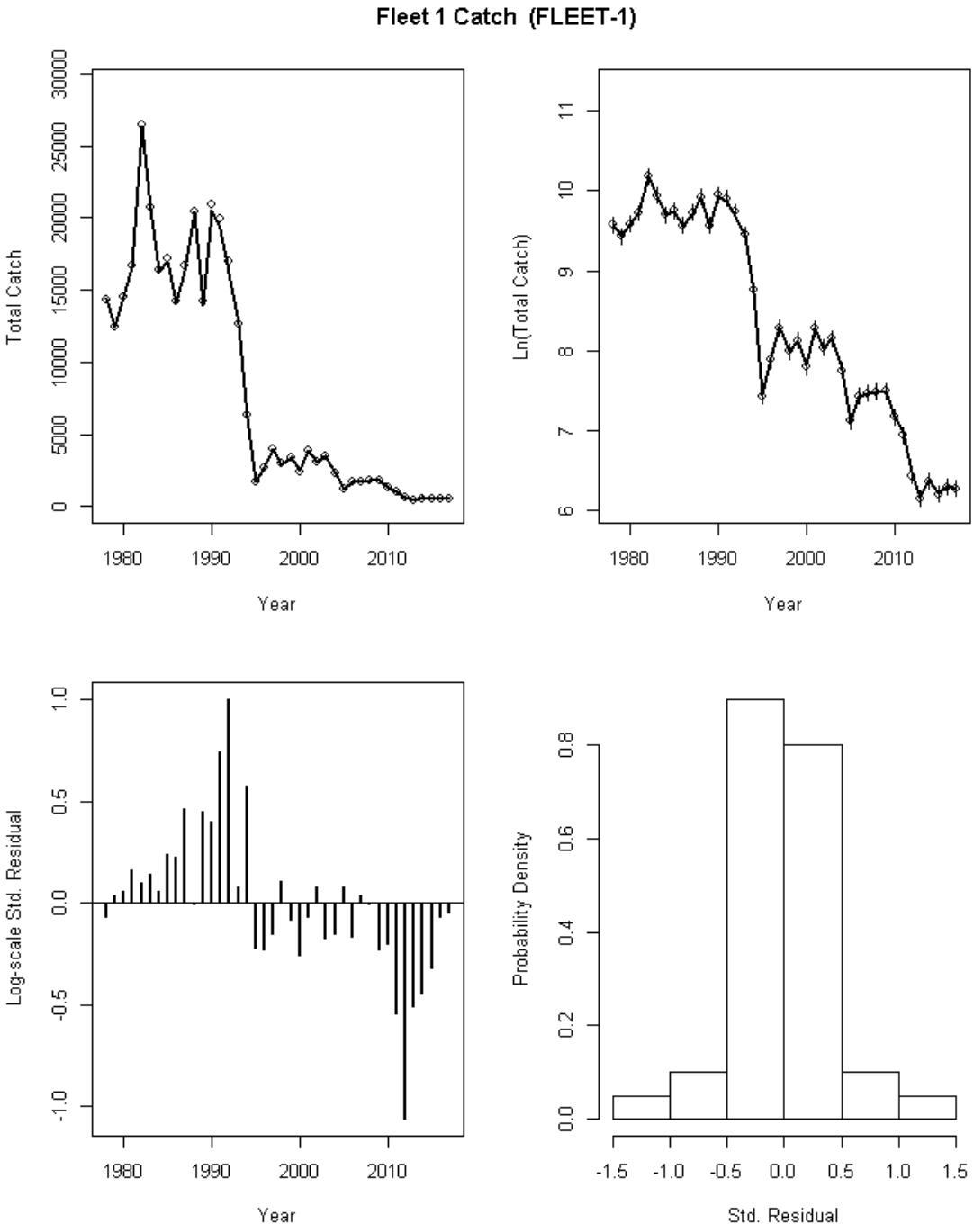
	Age									
Year	1	2	3	4	5	6	7	8	9	10+
1978	0.245	1.149	1.639	2.121	2.799	4.103	4.285	7.587	7.881	12.91
1979	0.564	0.8	1.386	2.601	3.477	4.954	7.137	7.347	9.036	14.36
1980	0.207	0.955	1.789	2.161	4.03	5.289	6.898	10.39	10.01	13.46
1981	0.331	0.697	1.572	2.603	3.731	5.675	7.101	8.17	11.54	15.92
1982	0.34	0.825	1.651	2.681	3.919	5.537	7.438	8.895	10.47	16.02
1983	0.674	0.909	1.699	2.572	4.077	5.529	7.262	9.298	10.64	15.04
1984	0.486	1.202	1.853	2.753	3.843	5.29	7.116	8.545	10.65	13.62
1985	0.337	0.945	1.705	2.712	3.946	5.322	6.938	8.93	10.03	13.76
1986	0.326	0.853	1.787	2.446	3.922	5.522	6.933	8.529	10.45	12.26
1987	0.41	0.886	1.797	3.086	4.215	5.908	7.662	8.744	10.18	13.81
1988	0.435	0.826	1.787	2.705	4.393	5.725	7.73	9.308	10.27	13.72
1989	0.391	0.889	1.516	2.706	3.877	5.437	6.434	9.003	10.29	14
1990	0.469	0.981	1.738	2.513	3.921	5.435	6.849	8.163	10.48	13
1991	0.544	1.027	1.937	2.732	3.695	5.041	6.711	8.587	9.494	14
1992	0.675	1.026	1.861	2.831	3.65	4.898	6.13	8.033	10.3	15
1993	0.403	1.097	1.723	2.544	3.773	4.787	6.186	7.504	8.896	12
1994	0.41	0.895	1.731	2.691	3.532	5.249	6.232	7.421	8.125	13
1995	0.153	0.893	1.682	2.679	4.119	5.293	8.052	8.482	9.223	17
1996	0.307	0.677	1.69	2.543	3.97	5.365	6.399	9.51	10.18	11
1997	0.475	0.852	1.715	2.518	3.43	5.023	6.505	7.303	10.14	11
1998	0.511	0.947	1.745	2.48	3.409	4.536	5.945	7.535	9.22	14
1999	0.341	0.952	1.625	2.579	3.413	4.666	5.78	7.05	8.566	14
2000	0.485	0.846	1.599	2.393	3.527	4.288	5.599	6.517	7.936	13
2001	0.087	0.75	1.566	2.323	3.221	4.423	4.954	6.449	7.654	11
2002	0.169	0.501	1.351	2.288	3.316	4.18	5.589	6.554	7.617	11
2003	0.138	0.638	1.598	2.303	3.169	4.123	5.167	6.622	7.924	9
2004	0.133	0.595	1.512	2.425	3.063	4.013	4.709	6.293	7.643	10
2005	0.312	0.45	1.387	2.079	3.113	3.948	4.703	5.941	7.556	10
2006	0.134	0.504	1.198	1.894	2.78	3.867	5.24	5.296	6.817	7
2007	0.277	0.526	1.016	2.006	2.626	3.588	5.109	6.458	6.318	10
2008	0.156	0.763	1.523	2.119	2.909	3.879	4.77	6.947	7.382	9
2009	0.475	0.582	1.559	2.596	3.215	4.055	5.374	6.259	8.897	11
2010	0.321	0.921	1.516	2.201	3.202	3.57	4.798	5.908	7.713	11
2011	0.179	0.719	1.486	2.283	2.98	3.803	3.812	5.564	7.738	10
2012	0.155	0.539	1.334	2.131	3.07	3.798	4.457	4.908	5.685	5.23
2013	0.191	0.539	1.313	2.141	3.137	4.233	4.695	5.222	6.706	7.174
2014	0.151	0.569	1.453	2.193	3.106	4.094	5.507	6.663	7.33	6.772
2015	0.302	0.592	1.391	2.595	3.228	4.21	5.858	9.102	9.275	6.371
2016	0.034	0.563	1.465	2.237	3.76	4.285	5.464	7.625	14.18	6.238
2017	0.096	0.38	1.155	2.257	3.509	5.276	5.642	6.446	9.237	6.357

Appendix.Table 2. ASAP model diagnostics and results.

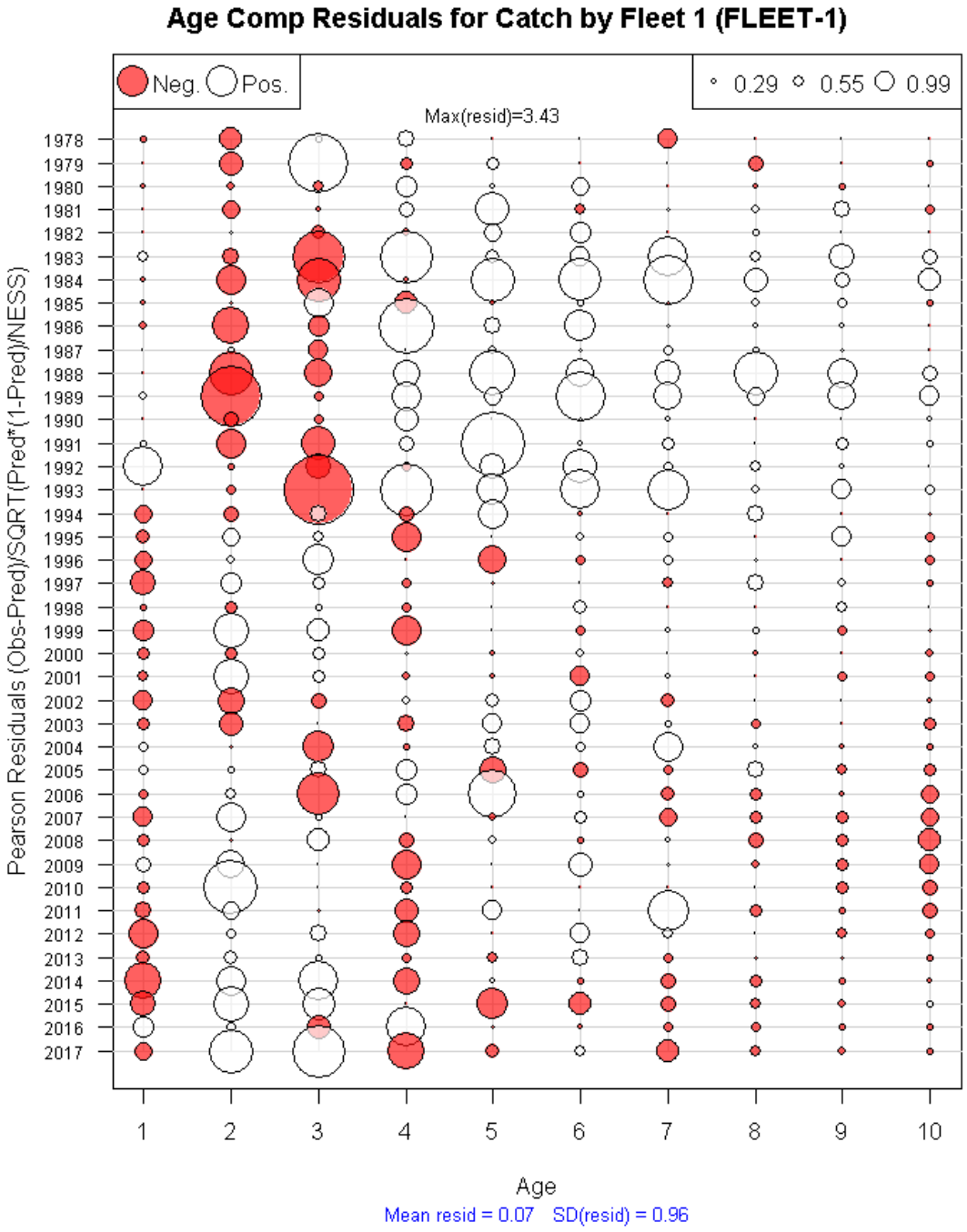
	SSB (mt)	F
Mohn's rho	0.76	-0.412
2017 Estimate	4,417	0.13
2017 rho adjusted	2,507	0.22

Appendix.Table 3. ASAP model run 8 results for January 1 biomass (ages 3+, mt), spawning stock biomass (SSB, mt), fishing mortality (F) and recruitment (age 1,000s fish).

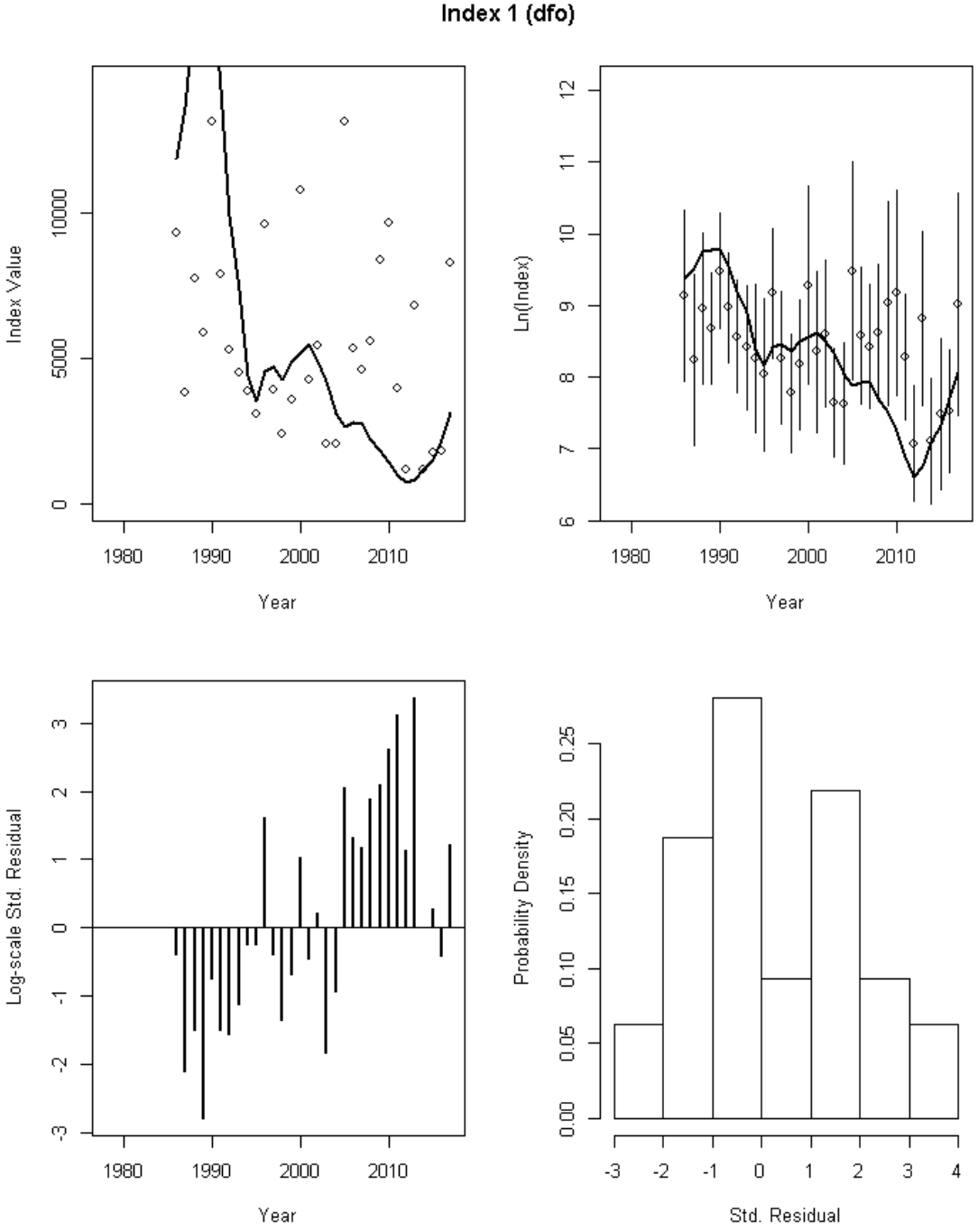
Year	Jan 1 B	SSB	F	Recr
1978	34109	30645	0.45	10932
1979	30803	28026	0.37	10534
1980	37338	33852	0.39	9095
1981	38706	34700	0.46	19389
1982	37250	31973	0.72	7445
1983	37476	32743	0.61	3598
1984	31207	27346	0.59	13682
1985	22809	19223	0.83	5401
1986	22792	19781	0.65	26268
1987	20420	17901	0.59	6500
1988	37717	32822	0.64	13938
1989	28516	25544	0.46	5752
1990	34796	30224	0.65	6823
1991	26891	22371	0.91	11549
1992	17709	14466	1.02	2563
1993	15768	12611	1.15	3074
1994	7877	6333	1.51	1959
1995	6554	6070	0.41	1227
1996	8072	7341	0.50	2606
1997	7594	6563	0.83	3508
1998	7167	6418	0.66	1225
1999	8854	7957	0.67	3410
2000	7786	7116	0.43	1537
2001	9443	8367	0.73	1055
2002	7770	6990	0.54	1488
2003	6831	5899	0.81	389
2004	5210	4583	0.73	2418
2005	3508	3171	0.47	421
2006	4269	3831	0.65	851
2007	3681	3230	0.70	1140
2008	3306	2888	0.77	517
2009	3363	2880	1.01	362
2010	2263	1909	1.07	482
2011	1462	1168	1.47	928
2012	922	763	1.41	626
2013	1206	1093	0.71	335
2014	1646	1494	0.57	2233
2015	1770	1640	0.32	967
2016	3727	3518	0.24	763
2017	4646	4417	0.13	1380



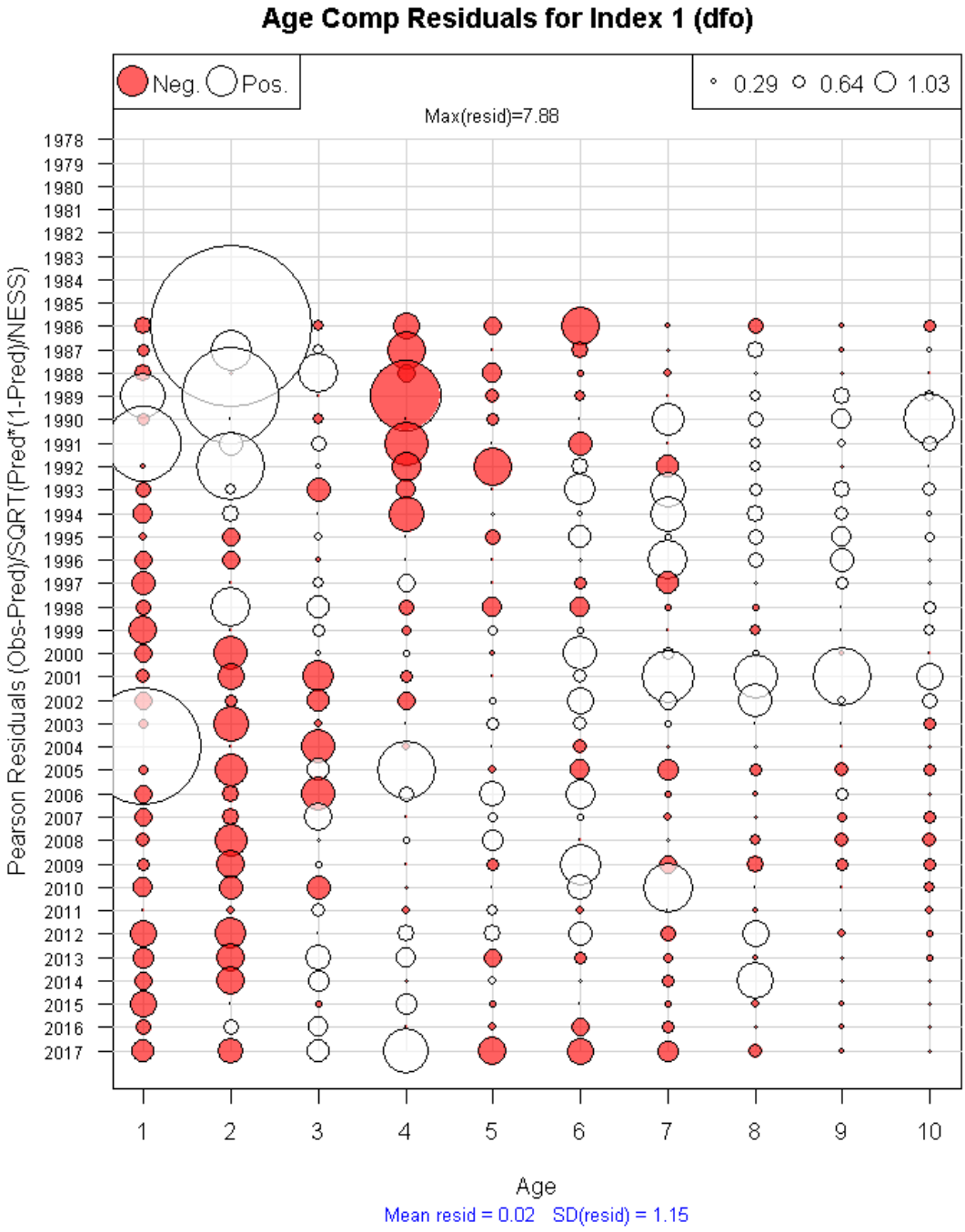
Appendix Figure 1. ASAP model fit to total catch of eastern Georges Bank cod.



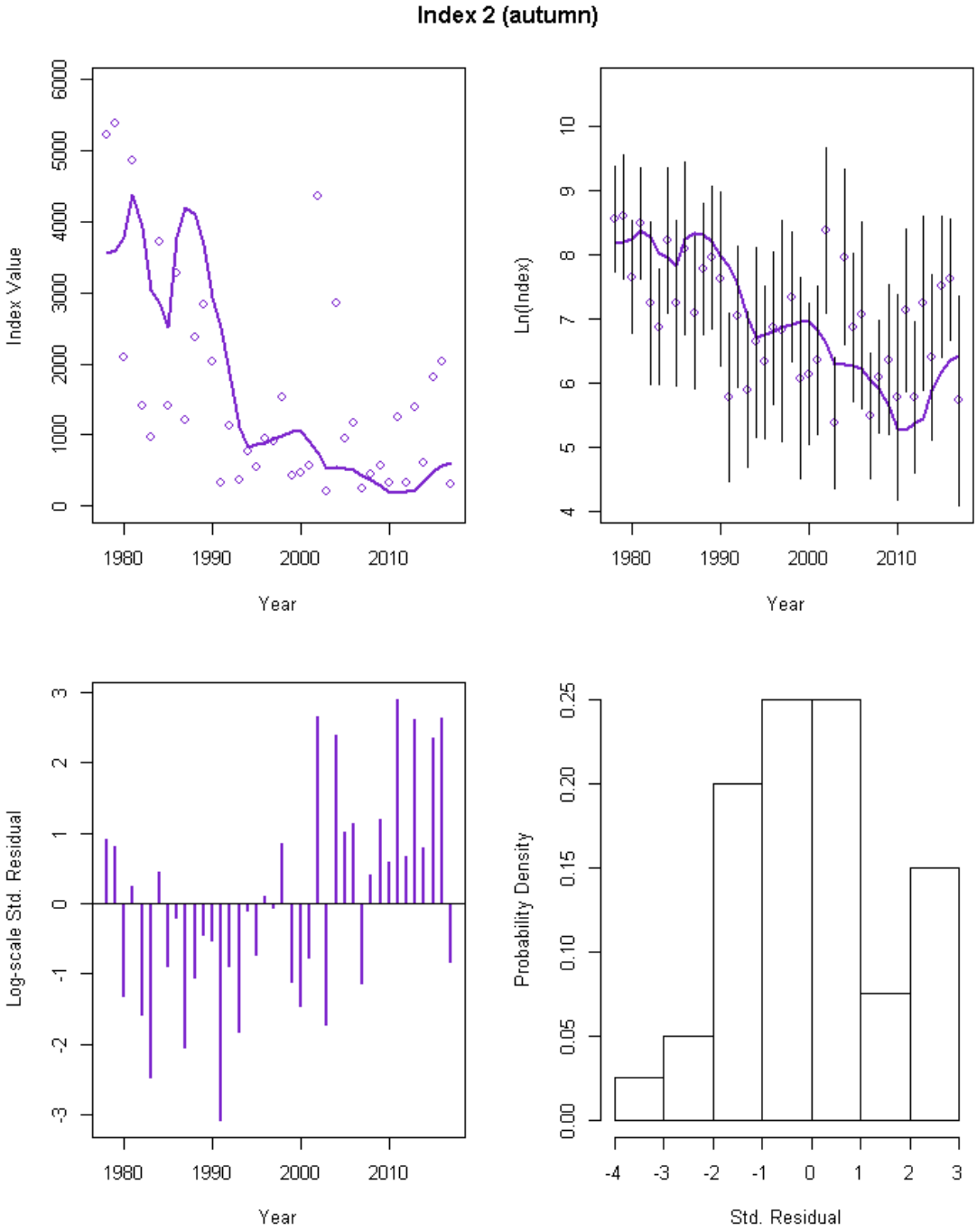
Appendix Figure 2. ASAP model residuals for the commercial catch age composition of eastern Georges Bank cod.



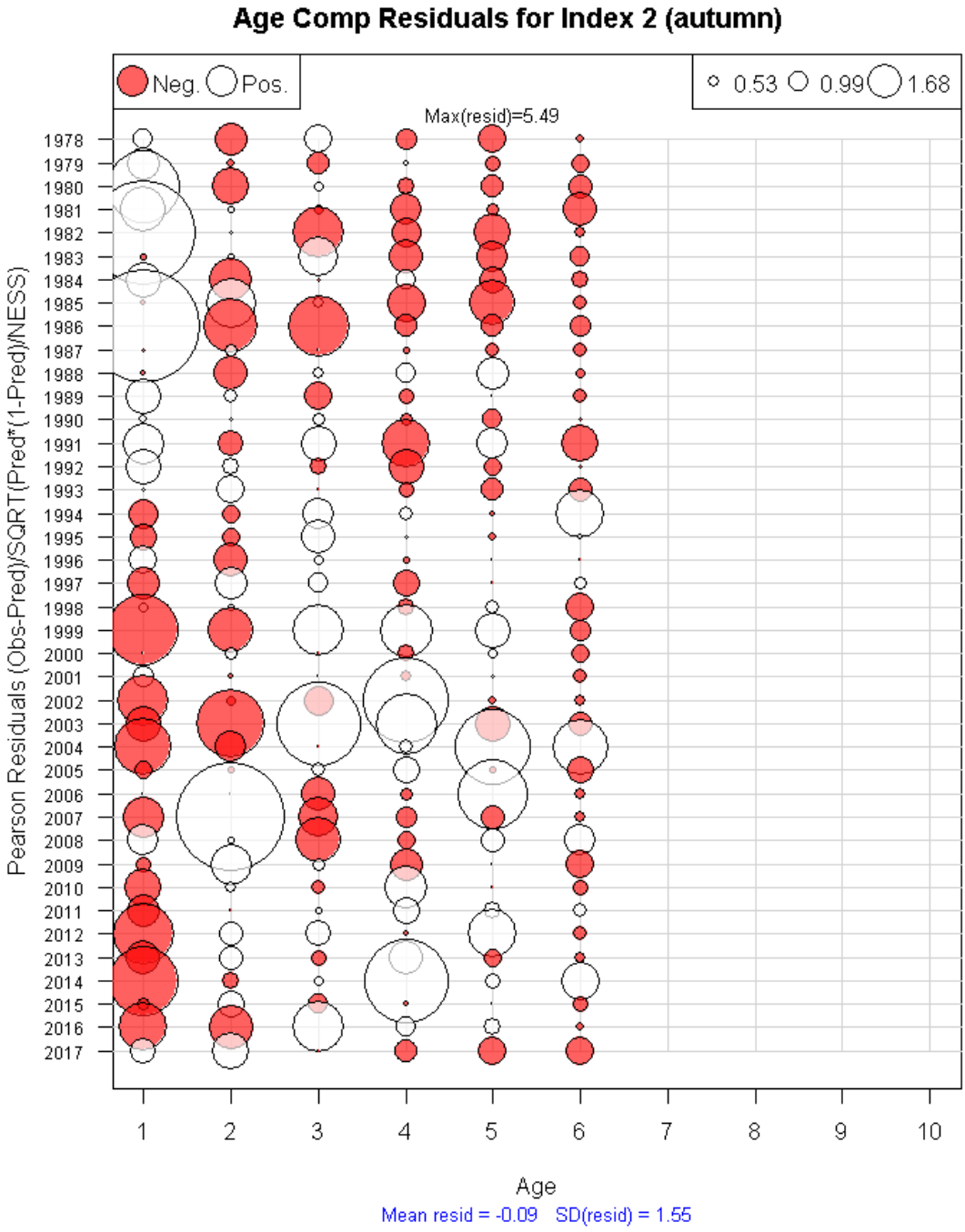
Appendix Figure 3. ASAP model fit to DFO survey indices of eastern Georges Bank cod.



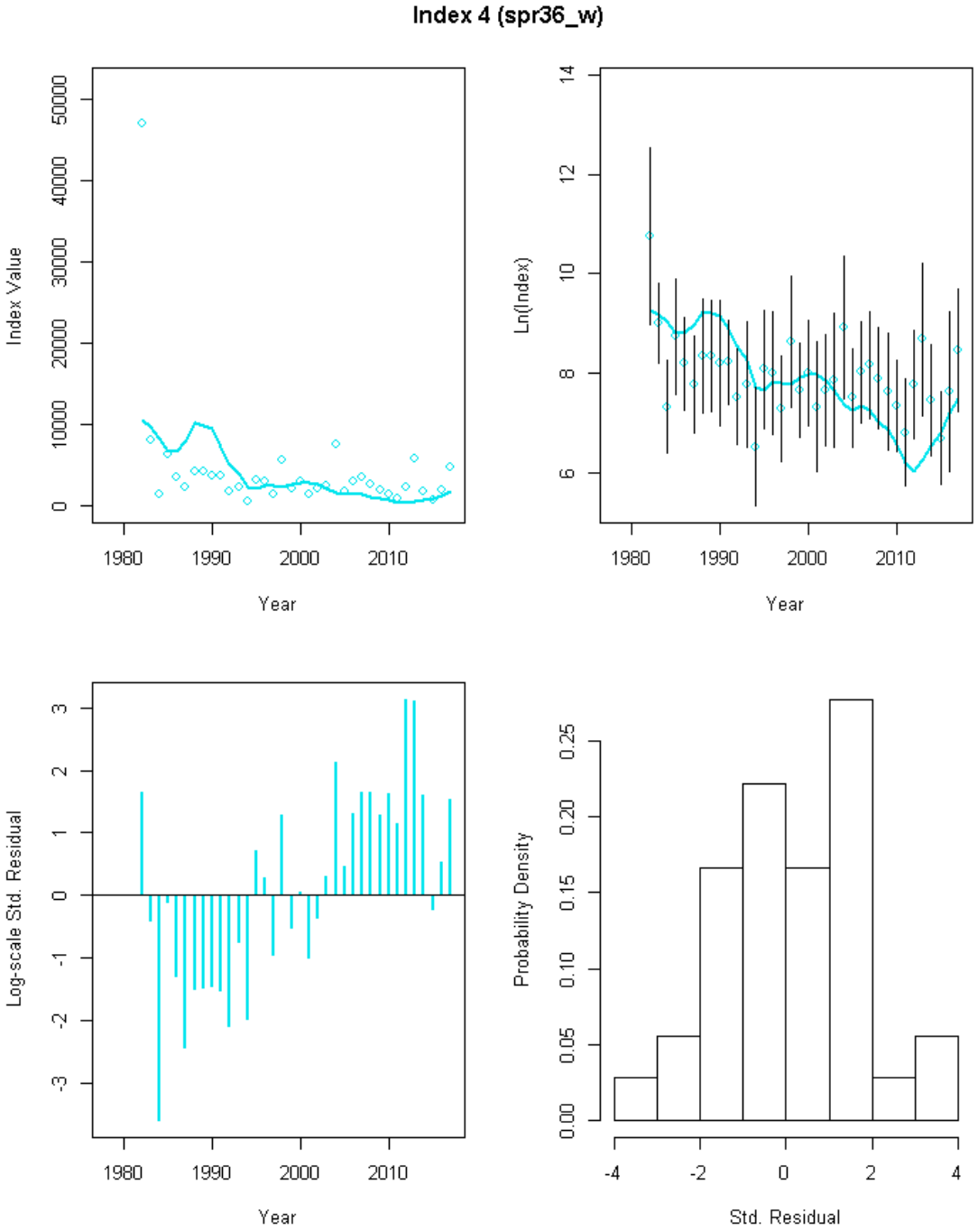
Appendix Figure 4. ASAP model run age composition residuals for DFO survey index of eastern Georges Bank cod.



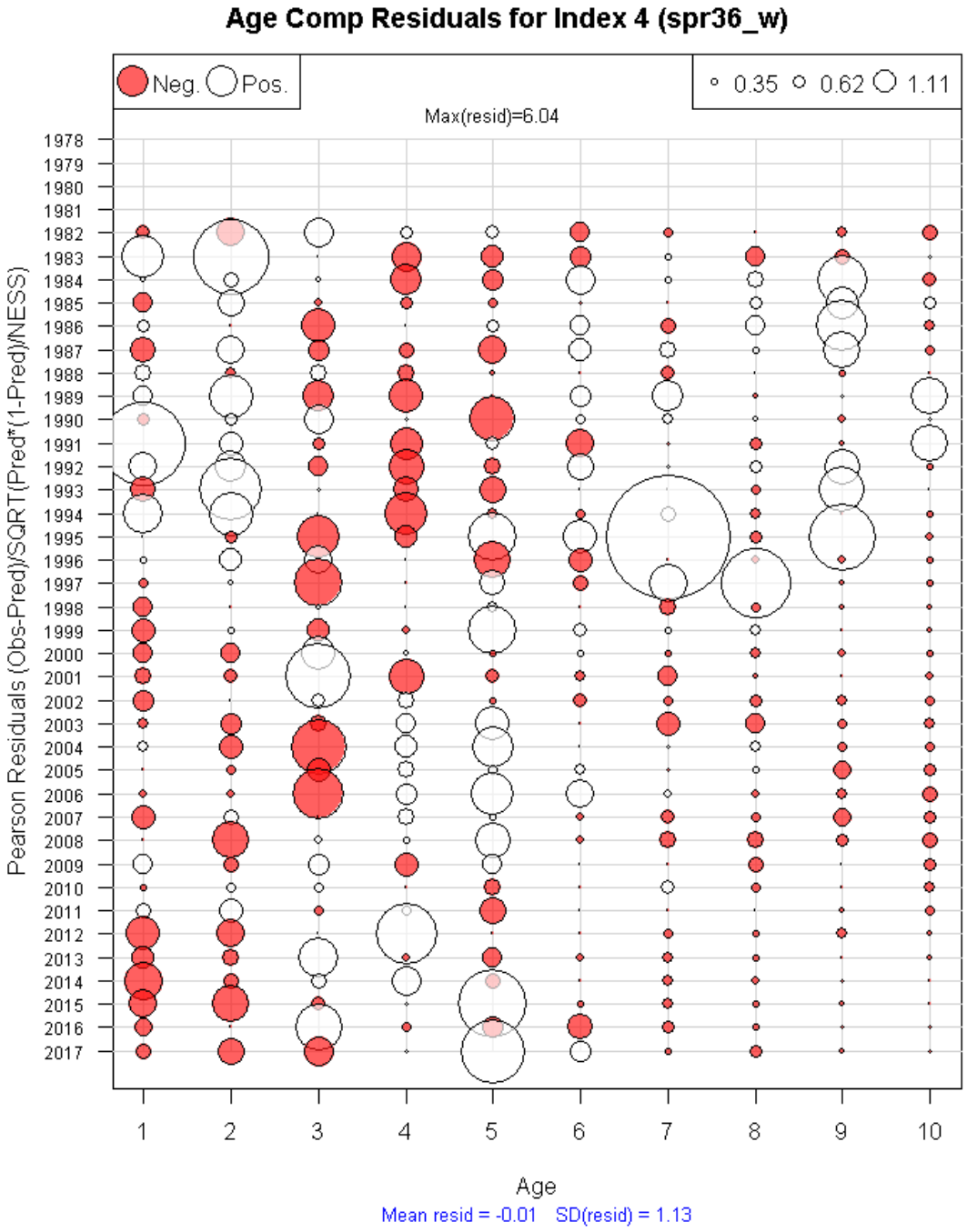
Appendix Figure 5. ASAP model fit to NEFSC autumn survey indices of eastern Georges Bank cod.



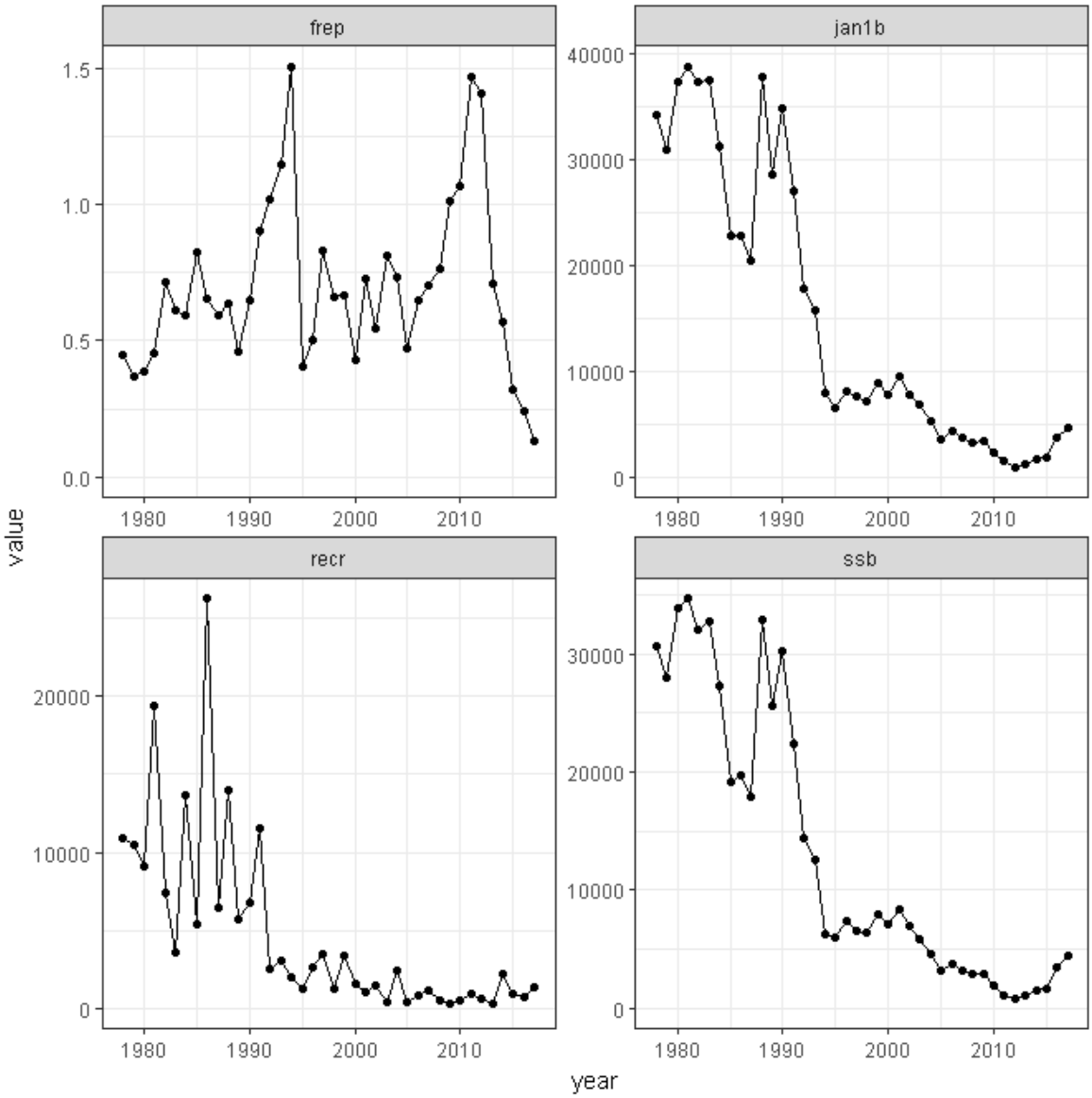
Appendix Figure 6. ASAP model age composition residuals for NEFSC autumn survey index of eastern Georges Bank cod, base (left panel) and run 8 (right panel), 1978-2017.



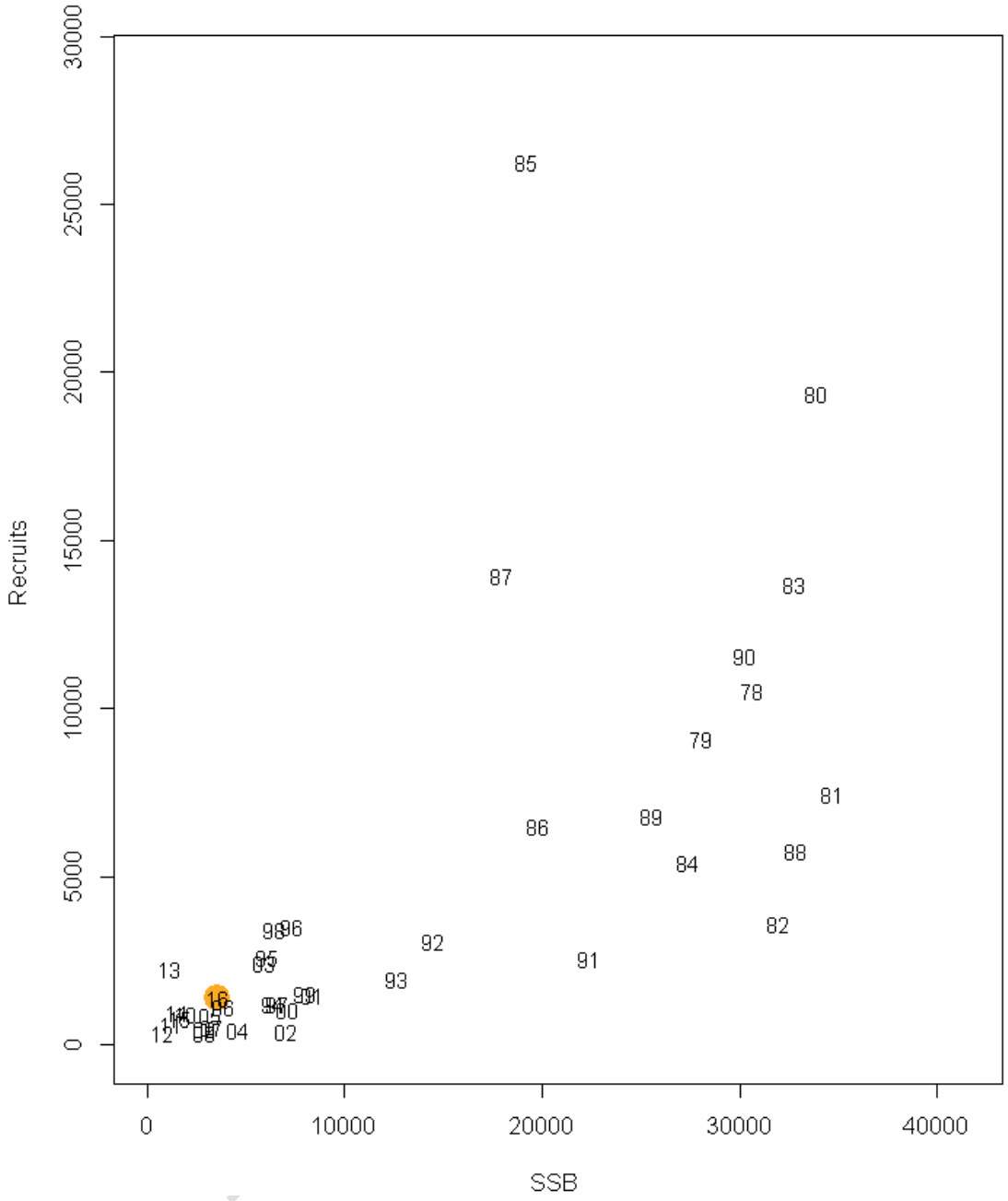
Appendix Figure 7. ASAP model fit to NEFSC spring Yankee #36 trawl survey indices of eastern Georges Bank cod.



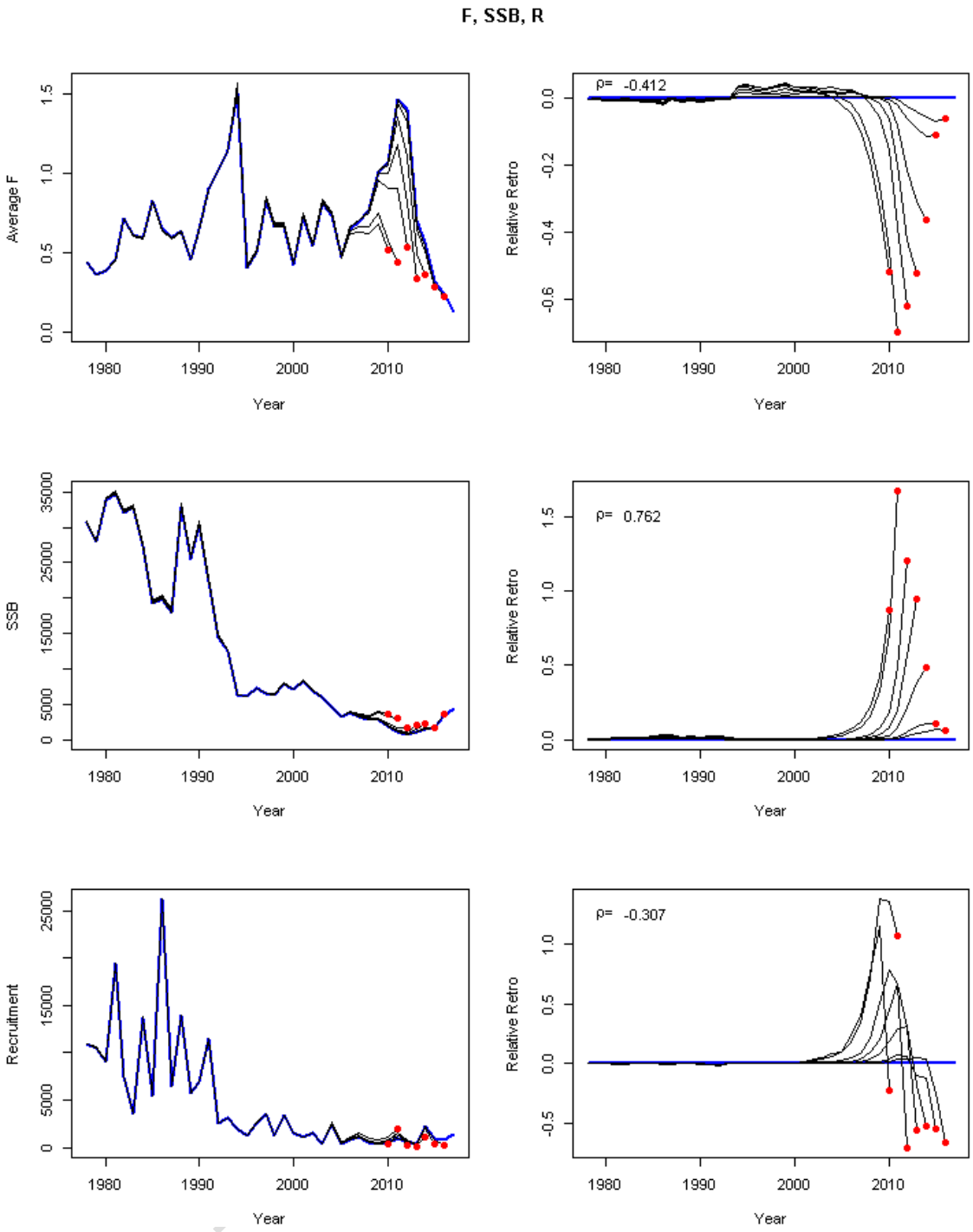
Appendix Figure 8. ASAP model age composition residuals for NEFSC spring Yankee #36 trawl survey index of eastern Georges Bank cod.



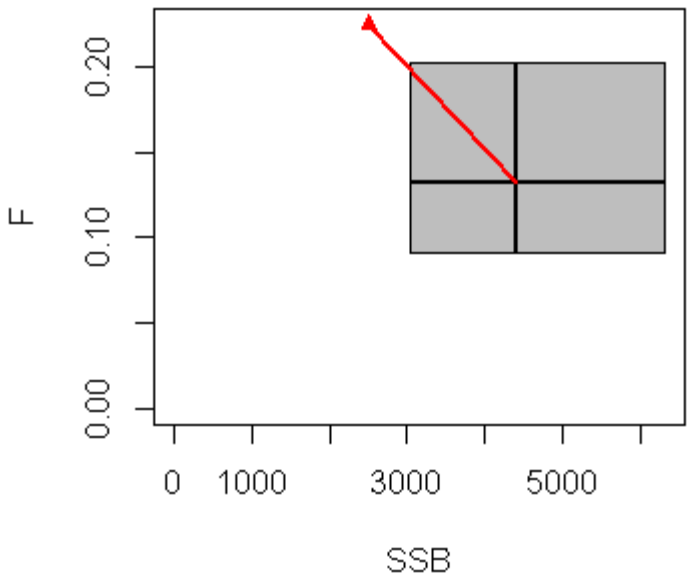
Appendix Figure 9. ASAP model results for fishing mortality (ages 5+), January 1 biomass (ages 3+, mt), spawning stock biomass (mt), and recruitment (age1, 000s fish).



Appendix Figure 10. ASAP stock – recruitment plot.



Appendix Figure 11. ASAP model results of retrospective bias of fishing mortality (F), spawning stock biomass (SSB), and age1 recruitment.



Appendix Figure 12. Terminal year ASAP estimates of spawning stock biomass (SSB) and fishing mortality (F) with respective 90% probability intervals, and the rho-adjusted value of SSB and F.